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ORIGINAL ARTICLES.

On the Presence of the Zones of *Anthracomya lenisulcata* and *Carbonicola ovalis* in the Culm Measures of North Devon.

By BRIAN SIMPSON, M.Sc., University College, Swansea.

(PLATE XXIII.)

THE age of the Culm Measures of North Devon and, in particular, those of the Bideford Area,[1] with which this paper is concerned, has long presented a difficult problem.

The rocks of the Bideford Area have been ascribed variously to the Millstone Grit, the Coal Measures, the Lower Coal Measures, and the Middle Coal Measures. The present research seems to place them in the Lower Coal Measures.

Thick sandstones, sandy shales, shales, and a little coal constitute the main rock-types in this area. They are striking generally east–west, and are folded into extremely sharp anticlines and synclines which pitch to the west. The rocks are intensely cleaved and, as would be expected, the shales have suffered more deformation than the sandstones, so that fossiliferous shales have had their fossil contents distorted beyond recognition in many places. However, in a few localities, fossils are relatively abundant and these are chiefly fresh-water lamellibranchs and plants. It is with the former that this paper is concerned, and their investigation has resulted in the recognition of the two zones described below.

The zones are well marked at two localities, the *lenisulcata* zone at Abbotsham Cliff, 1¾ miles south of Westward Ho, and the *ovalis* zone at Roberts Quarry, ½ mile east of East-the-Water, Bideford.

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[1] The writer wishes to acknowledge a grant from the Government Grants Committee of the Royal Society in aid of this work.

Zone of Anthracomya lenisulcata.

The fresh-water lamellibranchs of this zone are exposed, in a narrow band of blue-grey slightly siliceous mudstone, about 130 yards north of the outcrop of carbonaceous material—the Culm Bed—at Greenacliff. The shale weathers to a light grey colour with oxide of iron in occasional patches. A thick sandstone overlies the bed. Numerous specimens have been collected from this locality by the writer, and many more have been loaned by Mr. Inkermann Rogers, of Bideford. It is seen, therefore, that specimens are relatively abundant in this locality and the following species have been identified (see Plate XXIII, and Fig. 1) :—

Carbonicola aff. *pseudacuta* Trueman.
Carbonicola aff. *recta* Trueman.
Carbonicola cf. *ornata* Trueman.
Anthracomya cf. *bellula* Bolton.

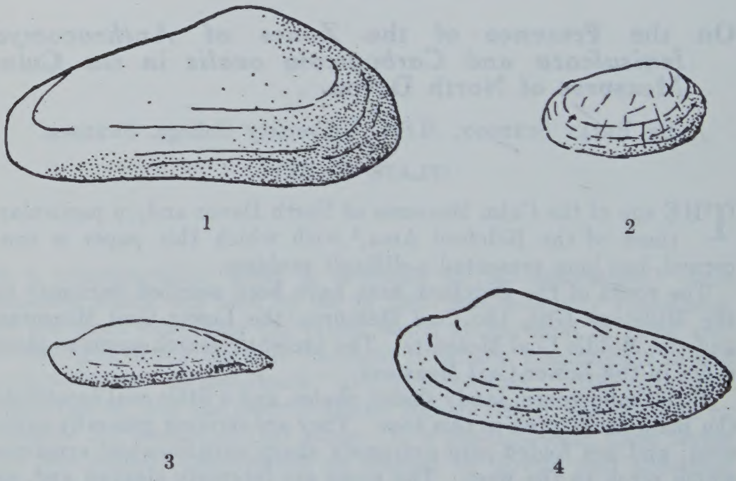

Fig. 1.—1. *Carbonicola* aff. *recta* Trueman. 2. *Anthracomya* cf. *bellula* Bolton. 3. *Carbonicola* cf. *aquilina* (J. de C. Sow.). 4. *Carbonicola* aff. *communis* D. and T. 1 and 2. Abbotsham Cliff. 3 and 4. Roberts Quarry.

Many very small specimens are present and appear to be immature specimens of *Carbonicola*.

The above assemblage was first recognized, as being characteristic of this zone, in Yorkshire (1),[1] the first three species being described from that area (2). *C.* aff. *pseudacuta* and *C.* aff. *recta* are the commonest species found. They occur as crushed forms in the shale, but the ornament is usually very well preserved. *C.* cf. *ornata* and *A.* cf. *bellula* are rather more rare, but in their case also the ornamentation is relatively well seen.

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[1] The numbers in parentheses refer to Bibliography at end of article.

In South Wales (3), the nearest known area where the zone occurs, this zone is now recognized as forming part of the strata hitherto placed in the Millstone Grit, whilst in Yorkshire, where it was first recognized, it includes part of the Lower Coal Measures and the upper portion of the Millstone Grit. It thus seems possible that the earlier workers in the Culm each had gleaned some trace of the truth, concerning the age relations, from various parts.

Zone of Carbonicola ovalis.

The fossil horizon exposed in Roberts Quarry appears to belong to the *ovalis* zone. The fossils are preserved in a blue-grey soapy shale about two feet thick which, as in the case of the *lenisulcata* shales, is overlain by a sandstone. The following species are recorded :—

C. aff. *rhomboidalis* Hind.
C. aff. *communis* Davies and Trueman.
C. cf. *aquilina* (J. de C. Sow.).
C. cf. *ovalis* (Martin).
Small carbonicolas.
A. cf. *lenisulcata* Trueman.

The most common species are *C.* cf. *rhomboidalis*, C. aff. *communis*, and *C.* cf. *aquilina*, whilst the remaining species are definitely rare.

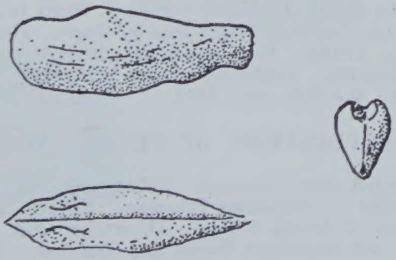

Fig. 2.—Small Carbonicola common in *ovalis* zone, Roberts Quarry. × 3.

A small *Carbonicola* (Fig. 2) figured below forms a very common element in the assemblage ; it is mostly preserved in the form of casts. As seen from the figure, the form is rather elongate and relatively stout. The umbones show the typical shape of the ovalis group, but its general form suggests that it belongs to the same group as *C. aquilina*. *Anthracomya* is represented by a specimen here figured and kindly loaned by Mr. Jenkinson, of the Bideford Museum. It has affinities with *A. lenisulcata*, but is rather more elongate than that form.

The assemblage described above is comparable with that found in parts of the *ovalis* zone in other areas of the Coal Measures (4), but it may well be from the lower part of that zone.

CONCLUSION.

From the presence of these two zones in the Bideford district it is evident that the strata there represented must be referred to the Lower Coal Measures, and that E. A. Newell Arber (5) was in error when on the plant evidence he wrote "the horizon in the Upper Carboniferous represented by the portion of Upper Culm Measures in which the coal or culm occurs in the Bideford district is equivalent to the Middle Coal Measures in other British coalfields", and that H. B. Woodward was right when he tentatively suggested that the measures were of Lower Coal Measure age. It is interesting to note in this connection that the conclusion reached by Arber, concerning the age of the beds, was in accord with that reached by R. H. Goode (7) in his investigation of the Millstone Grit of Pembrokeshire, he also ascribed the "so-called Millstone-Grit" to the Middle Coal Measures on plant evidence.

Finally, the writer wishes to thank Professor A. E. Trueman for identifying the species; Mr. Inkermann Rogers, for so kindly showing him over the area and loaning many specimens; and Mr. Alan Stuart for his pleasant company in the field.

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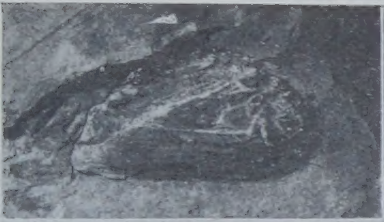
(1) D. A. Wray and A. E. Trueman. *Summary of Progress of Geological Survey*, pt. iii, 1930.
(2) A. E. Trueman. *Ann. and Mag. of Nat. Hist.*, **10**, iv.
(3) A. E. Trueman and W. D. Ware. *Proc. S. Wales Inst. of Engin.*, xlviii.
(4) A. E. Trueman. *Proc. S. Wales Inst. of Engin.*, xlix.
(5) E. A. Newell Arber. *Proc. Royal Soc.*, lxxiv.
(6) Inkermann Rogers. *Trans. Devon Ass.*, xli, 1909.
(7) R. H. Goode. *Q.J.G.S.*, lxix, 1913.

EXPLANATION OF PLATE XXIII.

FIG.
1.—*Carbonicola* aff. *recta* Trueman. Abbotsham Cliff.
2.—? *Anthracomya* cf. *lenisulcata* Trueman. Roberts Quarry.
3.—*Anthracomya* cf. *bellula* Bolton. Abbotsham Cliff.
4.—*Carbonicola* aff. *communis* Davies and Trueman. Roberts Quarry.
5.— „ cf. *ornata* Trueman. Abbotsham Cliff.
6.— „ aff. *rhomboidalis* Hind. Roberts Quarry.
7.— „ cf. *aquilina* (J. de C. Sow.). Roberts Quarry.
8.— „ aff. *ovalis* (Martin). Roberts Quarry.
9.— „ aff. *communis* Davies and Trueman. Roberts Quarry.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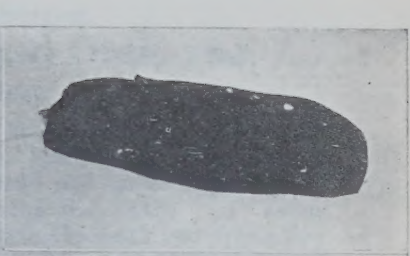
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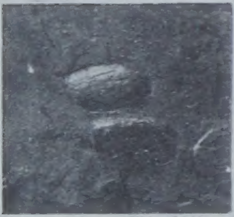
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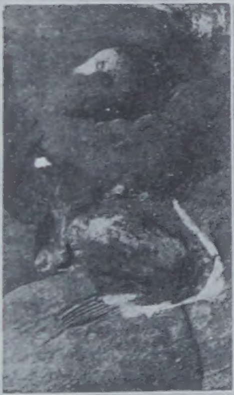
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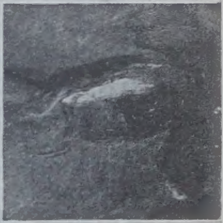
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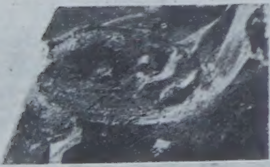
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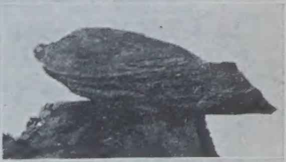
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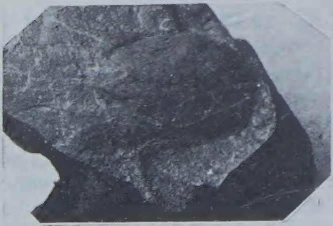
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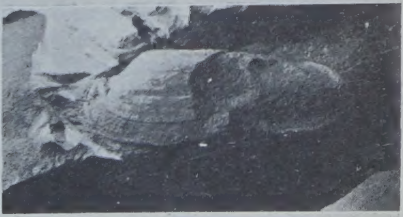
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Photo by T. C. Marchant.] [*To face p.* 436.

Fresh-water Lamellibranchs from the Culm Measures of N. Devon.

The Petrology of the Hecla Hook Formation in Central Spitsbergen.

By P. E. Fairbairn, B.A., B.Sc., A.R.S.M., F.G.S.

Introduction.

THE rock specimens described in this paper were collected by N. W. Pirie on the Cambridge Spitsbergen Expedition of 1930,[1] and by the writer on the second and larger expedition of 1932. They represent an area forming the "neck" of Central Spitsbergen between Klaas Billen Bay to the south and Wijde Bay to the north, together with an area to the east and north-east of the Mittag-Leffler Glacier, extending northwards to the upper portion of the Lomme Bay Glacier, thus including the Stubendorff Mountains to the east of Wijde Bay and the western flanks of the Chydenius Range. The 1930 expedition started from the mouth of Ebba Valley in Petunia Bay and reached Wijde Bay by way of the Ebba and Mittag-Leffler Glaciers; after reconnoitring part of the Stubendorff Glacier they returned over the Mittag-Leffler and Ragnar Glaciers, passing to the north-west of Mount Hult. Most of the ground was again covered by the 1932 expedition, but in addition a sledge party reached the highland ice of Garwood Land at the head of the Ebba Glacier, turned north along the eastern margin of the Mittag-Leffler Glacier system and passing to the west of the Newton-Chernishev massif succeeded in carrying out topographical and geological observations on the Lomme Bay Glacier, though these were much curtailed by bad weather. On the return journey the party made their way down the "Vallée de Martin Conway", crossed the divide between the Mittag-Leffler and Ebba Glaciers, and reached Petunia Bay by the same route that they had followed on the way up.

Both expeditions were under the leadership of R. M. Jackson: a detailed account of the 1932 expedition is to be published shortly.

General Geology of the District.

Pre-Devonian rocks on the mainland of Spitsbergen are confined to two north-south belts, one of which stretches up the west coast from South Cape to the neighbourhood of Magdalena Bay and Red Bay in the north and includes the narrow mountainous island of Prince Charles Foreland, while the other, to which belong the rocks here described, forms the central and western portion of the broad peninsula between Wijde Bay and Hinlopen Strait, and extends south to Klaas Billen Bay and Sassen Bay at the head of Ice Fjord, where it passes under horizontally bedded Carboniferous rocks. In both areas the dominant north-south strike has been determined by the Caledonian earth movements, which have thrown the beds

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[1] R. M. Jackson, "A Traverse from Ice Fjord to Wijde Bay, Spitsbergen": *Geogr. Jour.*, lxxviii, 1931, 277.

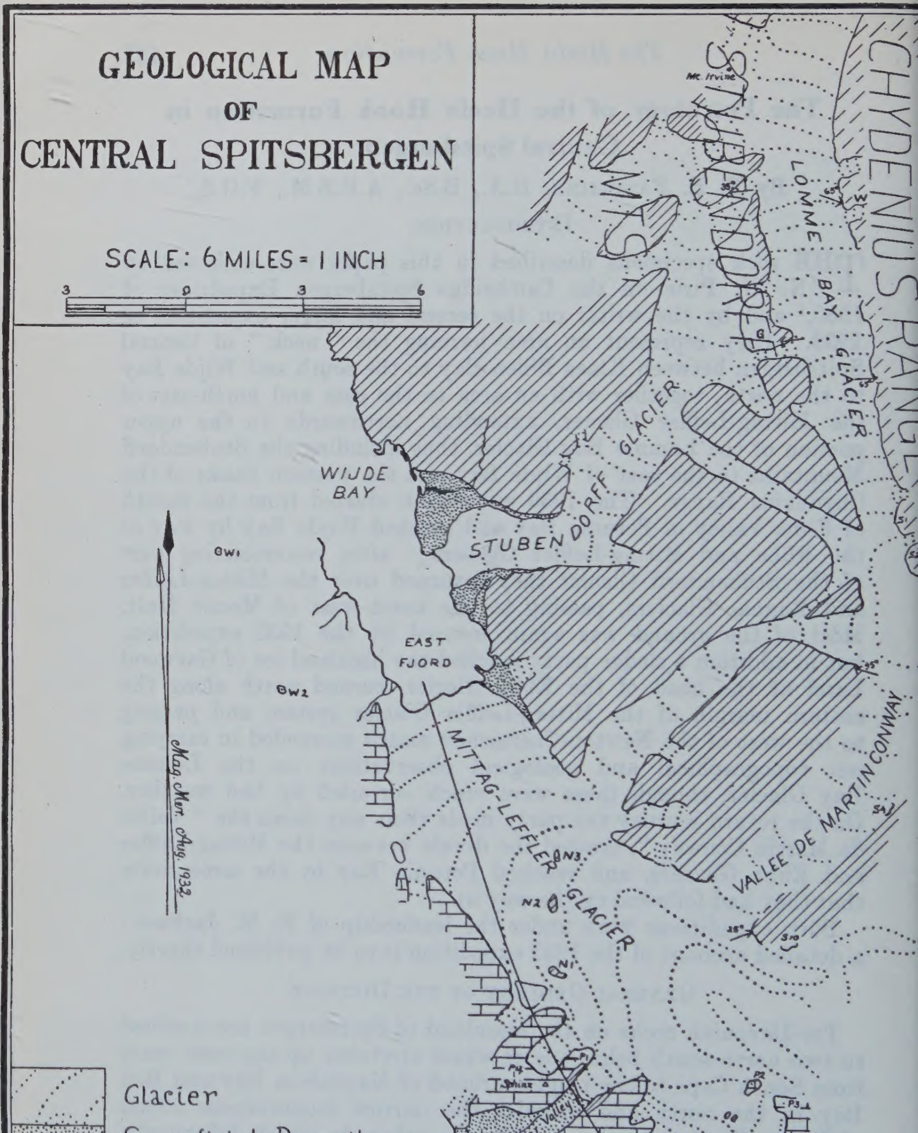

Fig. 1.—Geological Map of Central Spitsbergen.

into a complicated series of folds accompanied by varying degrees of metamorphism. In Central Spitsbergen these beds are sharply bounded to the west by a large strike fault dividing them from the Devonian beds on the west side of Wijde Bay and from the Carboniferous area to the west of the Mittag-Leffler Glacier. This fault, which is presumed to be of Tertiary age, dies out to the south; it is probably identical with that seen in the cliffs on both sides of Ebba Valley just below the glacier. Similarly to the east the relationship to the Carboniferous beds appears to be a faulted one, though in general the contact is much obscured by glaciers.

The pre-Devonian rocks of Spitsbergen were formerly thought to include two distinct formations, namely an older "Archaean" complex of gneisses, granite-gneisses, and schists, and a younger series of unfossiliferous slates, quartzites, limestones, and dolomites, to which the name of the Hecla Hook formation was given by A. E. Nordenskiöld,[1] after their development at Mt. Hecla Hook in Treurenberg Bay on the north coast. In Bear Island, between Spitsbergen and Norway, the discovery of fossils in lithologically similar beds enabled A. G. Nathorst [2] to fix their age as Ordovician, and O. Holtedahl [3] has shown that they represent a period of time from basal to middle Ordovician or, in Ulrich's classification, from the Ozarkian to the Black River division of the Mohawkian. That the so-called Archaean granites and gneisses were in reality younger than and intrusive into the Hecla Hook series was proved by Holtedahl and A. Hoel [4] from evidence found in the north-west of Spitsbergen. A transition from normal slates and quartzites through phyllites into mica-schists and augen-gneisses was observed by N. E. Odell [5] in the region of the Lomme Bay Glacier; and it seems highly probable that there is no Archaean at all in Spitsbergen, although the possibility of metamorphosed basal members of the Hecla Hook series being older than Ozarkian must be borne in mind. In the region under discussion the name Hecla Hook has been applied to all formations affected by the Caledonian earth movements, though for descriptive purposes it is convenient to distinguish the western schists and gneisses from the eastern slates and quartzites.

Petrological work on the Hecla Hook formation has been confined for the most part to the more accessible coastal regions. Its development at the head of Ice Fjord has been described in detail by

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[1] "Sketch of the Geology of Ice Sound and Bell Sound, Spitzbergen": GEOL. MAG., 2, III, 1876.

[2] "Beiträge zur Geologie der Bären-Insel, Spitzbergens, u. des König-Karl-Landes": *Bull. Geol. Inst. Upsala*, x, 1910–11.

[3] "On the Palaeozoic Series of Bear Island, especially on the Hecla Hook System": *Norsk Geol. Tidsskr.*, Bd. v, 1919.

[4] "New Features in the Geology of North-western Spitsbergen": *Am. Jour. Sci.*, 4, xxxvii, 1914.

[5] "The Geology of the Eastern Parts of Central Spitsbergen": *Q.J.G.S.*, lxxxiii, i, 1927.

G. W. Tyrrell,[1] whose paper gives reference to previous work. His descriptions are based on exposures in the Ragnar, Ebba, and Gips valleys, and on the north-west side of the Nordenskiöld Glacier, together with erratic boulders from the Nordenskiöld moraines: the rock types include slates, quartzites, quartz-schists and banded quartzose paragneisses, garnetiferous mica-schists, hornblende-schists and gneisses, crystalline limestones, lit-par-lit gneisses and augen-gneisses, and hornfels, with pegmatites and associated quartz veins. He has also recorded boulders of a syenitic suite of igneous rocks from the southern moraines of the Nordenskiöld Glacier; these were later found in place at the base of Mt. Terrier by Odell on the Oxford expedition of 1921. Many metamorphic types similar to the above were found inland by the Cambridge 1930 and 1932 expeditions, and it is the purpose of this paper to record their distribution and petrological characters.

Garwood Land, so called in memory of its original exploration by Sir Martin Conway and Professor E. J. Garwood in 1897, forms the southern part of the region described. This tract lies under a covering of "highland ice",[2] that is, an ice sheet of moderate thickness which reflects the underlying topography in a series of hills and valleys of low relief and which is held to represent an early stage in the waning of an "inland" or "continental" ice sheet such as that of Greenland of Antarctica. Rock peaks and ridges will rise to the surface in cases where their slope is too steep to support a permanent covering of ice, and thus lines of cliffs will be formed which may be invisible to an observer situated only a short distance behind them. This accounts for the unreliability of maps made from a distance, such as Vassiliyev's map of the district visited by the Russo-Swedish Arc-of-Meridian Expedition of 1899–1901.

To the north of Garwood Land rises the Lomme Bay Glacier, which flows approximately from south to north and separates the two parallel ranges of the Stubendorff Mountains to the west and the Chydenius Mountains to the east. Both ranges are composed of members of the Hecla Hook series, those forming the southernmost part of the Chydenius group having been invaded by a large mass of porphyritic granite, the "Chydenius massive", described by H. G. Backlund,[3] which forms the peaks of Mt. Newton and Mt. Chernishev, the former the highest measured summit in Spitsbergen.

The writer was able to investigate the exposures on either side of the Lomme Bay Glacier along that part to the south of Mt. Irvine, but found no additional evidence as to the relationship of the slates and quartzites which form the eastern wall to the highly contorted schists and gneisses of the Stubendorff Range. Both series strike approximately north-south (though individual measurements vary from 30° W. of N. to 20° E. of N.), and as this line of strike coincides with the direction of the glacier an important transitional zone is concealed. A few miles to the north, in the region investigated by Odell in 1923, the glacier takes a pronounced turn to the north-east and the basal members of the slate-quartzite series are clearly represented on the western wall; it is in this locality that the above-mentioned slate-phyllite-mica-schist transition was observed.

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[1] "The Pre-Devonian Basement Complex of Central Spitsbergen": *Trans. Royal Soc. Edin.*, **1**, liii, No. 10.

[2] For a detailed classification and discussion of the ice-forms met with in Spitsbergen, see G. W. Tyrrell, "The Glaciers of Spitsbergen": *Trans. Geol. Soc. Glasgow*, xvii, i, 1919–1922.

[3] "Mission Scientifique pour la Mesure d'un Arc de Méridien au Spitsberg" (R. ix B.).

Excluding the metamorphic series west of the Lomme Bay Glacier, the Hecla Hook formation in Central and East Central Spitsbergen has been classified by Odell as follows:—

UPPER SERIES.

(7) Cherty conglomerate.
(6) Black and white chert-horizon.
(5) Pale and dark dolomites and limestones of great thickness, often veined with calcite and dolomite, including an "intra-dolomite conglomerate" present in Bear Island, and a (?) fossil horizon of oolite and "oolitoid" rock or "Ryssö-dolomite".
(4) Red Shales, with thin quartzites and quartzose slates.

LOWER SERIES.

(3) Dark dolomitic limestones and pink and grey streaked marbles.
(2) Dark laminated shales or siltstones, hard buff-coloured and blue slates weathering green, often spotted and interbedded with pink quartzite.
(1) Purple massive quartzite
Pink massive quartzite } about 1,000 feet exposed.
Yellow massive quartzite

Owing to shortage of time it was impossible to make more than one short excursion across the dip of the slates and quartzites of the Chydenius Range, but the beds examined appear to belong to division 2 of the Lower Series, shales, siltstones, slates, and quartzites all being recorded. A section on the south side of Hill W showed 200 feet of dark blue-grey shale, with bands of a black papery variety, overlain by white quartzites weathering red, with green banded quartzitic grits. An exposure of hard black slate on a prominent bluff to the south appears to be continuous with a dark band capping above the hill and following directly on the quartzites, which are easily distinguishable from a distance by their light colour.

A similar section 5 miles to the south is of special interest in that it includes a well-marked sill of epidiorite, the significance of which is discussed below. This sill overlies a series, in ascending order, of white and grey quartzites, dark grey flaggy shales, and dark quartzites, the whole dipping slightly north of east at 65°.

No calcareous representatives were found, either in this series or further west. The massive quartzites which form the prominent cliff S3 may belong to division 1 of the Lower Series, but this is by no means certain.

Few conclusions as to the structure of these beds could be drawn. On the east wall of the Lomme Bay Glacier they possess a uniform easterly dip, but further to the east, in the neighbourhood of Mount Hope and the Bear Bay Glacier, Odell noted signs of isoclinal folding.

As regards the distribution of the western schists and gneisses, the writer was unable to examine the most highly metamorphosed types, which are developed in the Mittag-Leffler nunataks and along the east shore of East Fjord ; his knowledge of them is based on specimens collected by the Cambridge 1930 expedition. The most easterly member of the series is everywhere a medium-grained quartzo-felspathic paragneiss, locally rich in mica, and characterized by veins of quartz and pink orthoclase felspar. To the west comes a zone of amphibolites, with felspathic quartzites and quartz-schists, the latter types possessing a mineral composition similar to that of the paragneisses and owing their resinous appearance to a greater intensity of metamorphism. In this group the amphibolites predominate over the quartzites and quartz-schists, which form bands and lenses up to 15 feet in thickness. From the massive appearance of the amphibolites, which are clearly of basic igneous origin, it seems that the series is due to the metamorphism of massive basaltic flows with minor sedimentary intercalations, and it may be conjectured that the comparatively unaltered epidiorite recorded from the Chydenius Range represents a later hypabyssal member of the same igneous episode.

The increase in grade of metamorphism in passing from east to west across the strike of the Hecla Hook rocks culminates in the region of East Fjord and the Mittag-Leffler nunataks, where in addition to various examples of orthogneisses and quartz-felspar granulites a kyanite-bearing mica-schist was recorded by the 1930 expedition. The writer is indebted to Dr. N. W. Pirie for notes on localities and field occurrences in this area, which has yielded a considerable diversity of metamorphic types.

PETROLOGICAL DESCRIPTIONS.

1. *Western Schists and Gneisses.*

A. ROCKS OF IGNEOUS ORIGIN.

(*a*) *Amphibolites.* These are dense, dark-green to blackish rocks, usually possessing a regular well-marked schistosity. They form an important member of the western metamorphic zone and are especially well developed in the region of the Mittag-Leffler Glacier, where they are exposed in the steep cliffs at the junction with the Vallée de Martin Conway (near the point S9 of the 1930 survey), in N3, the most northernly of the three prominent nunataks on the Mittag-Leffler Glacier, and in the cliffs on the east side of East Fjord, just beyond the termination of the glacier. They were also identified by the writer further north in the Stubendorff Mountains, at the head of a small valley which runs in a westerly direction from the Lomme Bay Glacier, a little to the south of Mt. Irvine; and there is every reason to believe that these outcrops are part of a continuous belt stretching south to the neighbourhood of the Ebba and Nordenskiöld Glaciers, where they have been described by Tyrrell. Under the microscope the principal constituents are seen to be hornblende and alkali felspar, the former usually predominating. The felspar is invariably turbid and rarely shows multiple twinning; its precise determination is a matter of some difficulty, but it seems to vary from a medium oligoclase to a variety containing 95 per cent of albite. Clinozoisite is always present, sometimes accompanied by epidote, and biotite appears in a few instances, generally in the more felspathic varieties. Quartz occurs in most specimens, but is never abundant; accessory minerals are sphene, apatite, ilmenite, and rutile. Garnetiferous varieties occur chiefly in the western part of the belt, which has been subjected to a greater intensity of metamorphism; a number of these types are rich in biotite, quartz, and felspar, indicating derivation from some more acid types, perhaps of an andesitic or dioritic nature.

Two typical examples of these amphibolites were collected from the eastern cliffs of the Mittag-Leffler Glacier. The first (117) is a dark green rock with a columnar type of schistosity and veined with calcite. In thin section it is seen to consist mainly of green fibrous hornblende, with pleochroism $X =$ yellow, $Y =$ brownish-green, $Z =$ bluish-green, a mean refractive index about 1·655 and an extinction angle $Z \wedge c = 18°$. The felspar is albite; it occurs interstitially in small lenticular aggregates and is much decomposed. An important constituent is clinozoisite in small rounded grains and short prisms which show anomalous blue interference colours. Some dark bands are composed of aggregates of granular sphene. Quartz occurs sparingly in small xenoblastic grains and there is a little iron ore, partly altered to a reddish oxidation product. The section is traversed by small veins of calcite, albite, and chlorite.

The other example from this locality (113) has a more platy type of schistosity due to the presence of biotite, which is clearly visible in the hand specimen. Hornblende and felspar occur in roughly equal proportions; the hornblende shows a better development of crystal faces and is more strongly pleochroic than in the previous specimen, while the felspar is oligoclase and is comparatively unaltered. Biotite occurs in thin flakes intergrown with the hornblende; it is strongly pleochroic from pale yellow to reddish-brown and contains small inclusions of sphene. Quartz occurs in fairly large grains with a patchy distribution. Accessory minerals are clinozoisite, dark nearly opaque sphene, apatite, and ilmenite, the last associated locally with rutile. This rock is clearly derived from a more acid type, probably of andesitic character.

An amphibolite (34) from the shore of East Fjord shows the production of retrograde chlorite and calcite at the expense of the hornblende. The chlorite, which is mainly concentrated in veins, occurs as pale green aggregates giving brush polarization in dark browns; it is of the ripidolite type with a mean refractive index of 1·617. Epidote and clinozoisite are both present in idioblastic grains; the felspar is albite, and additional minerals are quartz, sphene, and ilmenite.

From N3, the most northerly of the three nunataks on the Mittag-Leffler Glacier, comes a felspathic variety of biotite-amphibolite (40), with albite ($Ab_{95}An_5$) and hornblende in roughly equal proportions, and characterized by the complete absence of quartz. The albite, which shows multiple twinning, is mainly turbid, though the interior of a crystal tends to be less altered than the margin; some crystals show clear borders and patches which appear to be of later formation. The hornblende is a pale variety with the usual pleochroism, a mean refractive index of 1·67 and extinction angle $Z \wedge c = 26°$; it encloses small grains of albite and is locally altered to a pale green chlorite. Biotite occurs in ragged flakes intergrown with the hornblende and bleached marginally; accessory minerals include sphene (often enclosing grains of rutile), clinozoisite, a little calcite, partly oxidized iron ore, and apatite.

A variety of amphibolite rich in garnet (36) was collected by the 1930 expedition from the intensely metamorphosed zone to the east of East Fjord. This is a dark heavy micaceous rock with a planar type of schistosity, and contains pink garnets up to $\frac{1}{4}$ in. in diameter. Under the microscope the garnets are seen to be full of inclusions of quartz, and show an incipient alteration to a fine-grained aggregate of chlorite and epidote. Quartz is specially abundant near the margin of the garnets, having clearly been expelled by them as crystallization proceeded. The hornblende is bright green, with inclusions of quartz and epidote, and altered to chlorite along cracks. Biotite occurs in stout well-developed flakes with a tendency to cluster round the garnets; these flakes can be seen cutting across the boundaries between adjacent hornblende or quartz crystals. The felspar is oligoclase and is unusually clear, only the crystal margins having undergone any alteration. Quartz occurs abundantly in irregular interlocking grains, and ilmenite is an important accessory mineral, while rutile can be seen arising from ilmenite, hornblende, and biotite.

Further east a garnetiferous amphibolite (111) was collected by the writer from the head of a valley leading west from the main Lomme Bay Glacier, a little to the south of Mt. Irvine. Exposures of this rock are more shattered and jointed than further south along the strike; the rock itself is much veined with calcite and ferruginous material and is not markedly schistose. Here the hornblende is of the usual type, with $X =$ pale yellowish green, $Y =$ grass green, $Z =$ pale bluish green, the distribution of colour being rather uneven. The garnets are small and irregularly shaped, and show every stage in the diapthoretic change to pale green chlorite marginally and along cracks. The remaining constituents, oligoclase, clinozoisite, a little quartz, calcite, sphene, and iron ore, are similar to those examples already described.

(*b*) *Biotite-oligoclase schist.*—(114) An example of this type occurs in the steep cliffs at the south-west end of the Vallée de Martin Conway, where it forms a narrow band 2 inches thick in quartz-schist. It is a dark phyllitic rock with thin veins and lenticles of quartz; under the microscope it is seen to possess a distinctive mineralogical composition, consisting predominantly of biotite and oligoclase, with short well-formed prisms of epidote and clinozoisite. Biotite is in excess of the felspar; it forms well-shaped folia, strongly pleochroic from pale yellow to brownish-green, and is locally chloritized, chiefly at the margins. The felspar, which is clear and unaltered, is identified as oligoclase by its nearly straight extinction on albite lamellae. Epidote and clinozoisite are both abundant and may enclose small grains of quartz, which however occurs only sparingly and tends to be concentrated in veinlets. Accessory minerals are sphene, apatite, and pyrite, the latter visible in hand specimens. This rock corresponds closely to Grubenmann's division of the "Biotitplagioklasschiefer",[1] examples of which have been described from the St. Gotthard district of the Alps and which are held to be of lamprophyric origin.

(*c*) *Garnetiferous hornblende-biotite-albite gneiss.*—(32) This rock forms a band 1 foot wide in amphibolite on the east shore of East Fjord. It is a light grey medium-grained gneissic rock containing red garnets up to $\frac{1}{8}$ in. in diameter, though N. W. Pirie reports the occurrence of others up to $\frac{1}{2}$ in. Under the microscope it is seen to consist of a sutured granoblastic aggregate of quartz and a twinned plagioclase felspar which is identified as albite of composition $Ab_{95}An_5$. The garnets are skeletal, with inclusions of quartz, albite, hornblende, and biotite. The hornblende is a highly coloured variety with $X =$ yellow, $Y =$ dark green, $Z =$ deep bluish green, $Z \wedge c = 24°$; it shows idioblastic outlines against biotite, the latter occurring in small somewhat decomposed flakes, the alteration of which has given rise to magnetite. Muscovite is visible in the hand specimen but is patchily distributed, and none can be distinguished in the slice. Orthite occurs in rounded, yellow, faintly pleochroic grains, and there is a little sphene, zircon, apatite, and pyrite. The general composition is that of a quartz-diorite, but there is some evidence that lit-par-lit injection has taken place in this area, and the rock may well be of hybrid origin.

(*d*) *Granite-gneisses.*—A coarse pink biotite-orthoclase-oligoclase gneiss has been recorded from the nunatak N3 on the Mittag-Leffler Glacier and from the interior of the Stubendorff Mountains near Mt. Irvine. A thin section shows pronounced cataclastic structure, with irregular bands of finely granular quartz and felspar interspersed with coarser-grained areas. Oligoclase is subordinate to orthoclase, and a little microcline is also present. The most abundant ferromagnesian mineral is biotite, which occurs in small greenish flakes showing almost complete absorption for rays vibrating parallel to the cleavage. Some of these flakes show opaque interiors and others enclose rounded grains of epidote, which with orthite is a fairly abundant accessory. Other constituents are a little sphene and chlorite, the latter secondary after biotite, and pyrite. From its appearance and mineralogical composition this rock is clearly of igneous origin, but the writer was unable to investigate its occurrence in the field, and only a single small specimen was available for examination. It is possible, as in the case of specimen No. 32, that some admixture of basic material with granitic magma has taken place, especially as amphibolites are known to be a constituent of the same nunatak. The specimen (120) from near Mt. Irvine contains elongated and shattered pink garnets up to ¼ in. in length, crowded with inclusions of quartz and biotite. One large porphyroblast of albite-oligoclase contains small poeciloblastic inclusions of quartz and is intergrown marginally with orthoclase. Small patches of a colourless isotropic mineral with low refractive index are referable to fluorspar. The effect of stress subsequent to the main crystallization is seen in parallel rows of minute inclusions which pass uninterruptedly through adjacent crystals.

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[1] U. Grubenmann, *Die Kristallinen Schiefer* (2nd ed., 1910), 241. A. Harker, *Metamorphism* (1st ed., 1932), 296.

From the moraine of the Stubendorff Glacier comes a massive pink fine-grained rock (37) with peculiar segregations and clots of mafic minerals which may measure as much as ½ in. across. These clots are only slightly elongated in one direction and the rock is best described as a hornblende-biotite-granulite. In thin section it shows unmistakable signs of crushing, large partially rounded blastoporphyritic felspars being set in a granoblastic quartz-felspar mosaic. Much of the felspar is cryptoperthite and is presumably original. The dark clots are seen to consist of small flakes of a yellowish, strongly pleochroic biotite and a deep greenish-blue hornblende, the latter preponderating, with grains of iron ore commonly surrounded by a rim of granular sphene.

B. ROCKS OF SEDIMENTARY ORIGIN.

(*a*) *Argillaceous types.*—Few examples of this class were found in the western area, where the majority of the members are of a quartzo-felspathic nature.

A garnetiferous mica-schist (110) occurs interbedded with muscovite-paragneiss and quartzite on the south side of Hill G, on the west wall of the Lomme Bay Glacier. This rock is highly contorted and shows a pronounced platy type of schistosity, with muscovite and biotite plainly visible in the hand specimen and abundant small garnets up to ⅛ in. in diameter. In thin section bands consisting predominantly of muscovite with a little biotite and iron ore are seen to alternate with others containing quartz and muscovite in roughly equal proportions and others consisting almost entirely of quartz with a few flakes of biotite. The garnets tend to occur in those bands which are rich in muscovite, flakes of which wrap round them: they show a fair development of crystal faces and are full of inclusions of quartz, biotite, and iron ore, sometimes with the suggestion of a spiral arrangement. They also show a marginal alteration to greenish chlorite, this change being complete in some of the smaller crystals. The biotite is pleochroic in yellows and reddish-browns, with pronounced haloes round minute crystals of zircon, and is partly chloritized. One band contains turbid crystals of orthoclase. Accessory minerals are iron ore and apatite, with a little blue tourmaline.

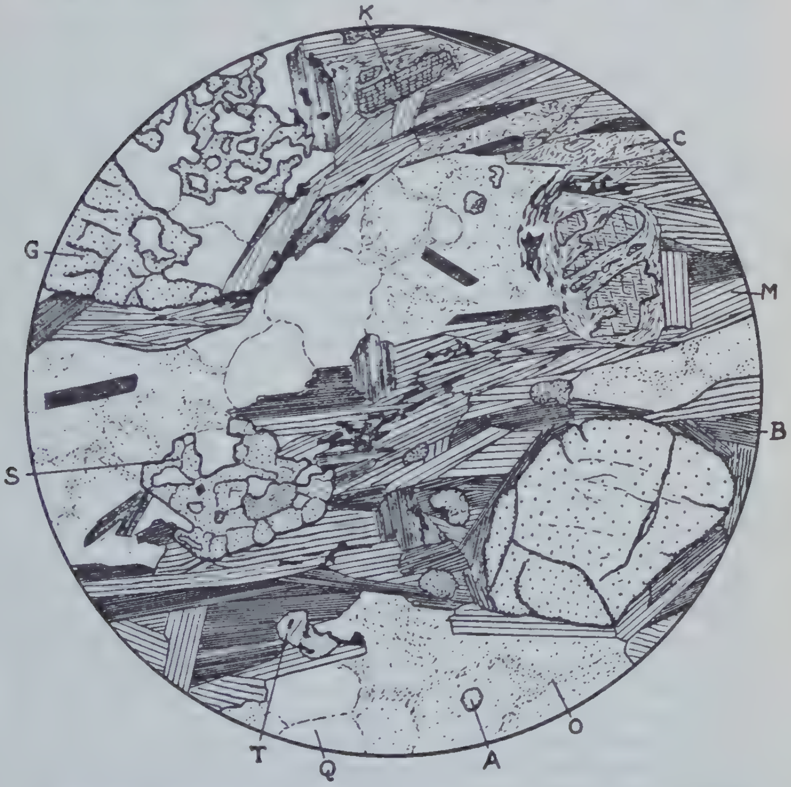

FIG. 2.—Kyanite-staurolite-garnet-mica-schist (31). East Fjord. × 14. A = apatite; B = biotite; C = chlorite; G = garnet; K = kyanite; M = muscovite; O = oligoclase; Q = quartz; S = staurolite; T = tourmaline.

Further west, from the highly metamorphosed district of East Fjord, comes a kyanite-staurolite-garnet-mica-schist (31, Fig. 2);

this rock is more coarsely crystalline than the above and contains garnets ¼ in. in diameter. A section cut perpendicular to the cleavage shows kyanite chiefly in basal sections, which show one good and one moderate cleavage inclined at 106°, extinction parallel to the good cleavage, and a birefringence similar to that of quartz. Some crystals are altering along cracks to a greenish chlorite. The crystals are porphyroblastic, the disposition of the surrounding flakes of mica indicating some movement subsequent to the formation of the kyanite. Staurolite occurs in pale yellow, faintly pleochroic crystals, occasionally showing hexagonal outlines and enclosing quartz and tourmaline. The garnets are traversed by irregular cracks and enclose quartz, biotite, and rutile. Small golden-yellow basal sections of tourmaline are identified by a uniaxial negative interference figure. The remainder of the rock is made up of sub-parallel folia of muscovite and biotite up to ⅛ in. in length, locally intergrown with sheaves of a pale green penninite chlorite, polarizing in ultra-blues, which is clearly secondary after biotite. The biotite is occasionally altered to grains and streaks of iron ore ; it is subordinate to muscovite and shows a tendency to cluster round the garnets. Quartz and oligoclase occur in streaks and augen-shaped aggregates, and there is a little accessory iron ore, apatite, and rutile.

(*b*) *Quartzo-felspathic types.*—A distinctive muscovite-bearing paragneiss, already recorded by Tyrrell from the Ebba Valley, forms a well-marked band on the eastern margin of the metamorphic belt ; it can be traced from a small outcrop near the head of the Mittag-Leffler Glacier northwards to the Vallée de Martin Conway, forming the prominent rock face S4, and further on to the Lomme Bay Glacier, where it forms the whole of the western wall as far as Mt. Irvine, having been recorded there by Odell in 1923. Tyrrell comments on their resemblance to certain types from the Moine series of the N.W. Highlands of Scotland. They are commonly cut by veins of quartz and pink orthoclase felspar, which have given rise to a development of biotite, often in large flakes, in those parts of the rock in which they are most abundant.

In the hand specimen these paragneisses are dark-grey, medium to fine-grained rocks, and are characterized by small augen of pink felspar up to ¼ in. in length and by a variable content of white mica ; they show a pronounced foliation but are not schistose. Under the microscope the constituents are seen to be quartz, orthoclase, and albite-oligoclase, with two micas, muscovite predominating ; accessory minerals are epidote, clinozoisite, sphene, apatite, and iron ore, with occasional small garnets.

A specimen from S4 (109) consists of a fine-grained aggregate of quartz and an acid oligoclase felspar, mainly untwinned but easily distinguished in ordinary light from quartz by its lower refractive index and slight turbidity. These two minerals form irregular interlocking grains, commonly elongated in the direction of foliation, both locally reaching porphyroblastic dimensions; augen-shaped aggregates of felspar are common. Muscovite and biotite are both present, muscovite in larger flakes than biotite; the latter occurs as small wisps, often wrapping round the felspar augen, and appears to have risen from chlorite, some of which is still visible. Clinozoisite is abundant, and one small isotropic crystal is identified as garnet; minor accessories are sphene, apatite, and a little iron ore.

Another specimen (112) from a locality some 5 miles further north along the strike is of similar composition, but shows a finely banded structure, areas rich in muscovite and biotite being separated by narrow bands and lenticles consisting mainly of quartz, with subordinate felspar, often porphyroblastic and showing a characteristic type of twinning.

Interbedded with normal paragneisses on the south side of Hill "G" is a garnetiferous variety (108), which forms a transition to the argillaceous type already described. This rock possesses a rude schistosity due to the concentration of flakes of muscovite along certain definite bands, and is of coarser grain than the normal type. The garnets are small and of sporadic occurrence; magnetite is an important accessory mineral.

Further west a well-defined group of quartz-schists and quartzites occur interbedded with amphibolites in the region of the Mittag-Leffler Glacier. The quartz-schists have been described from Klaas Billen Bay by Tyrrell as "pinkish glistening rocks, the schistosity planes of which are spangled with orientated flakes of white mica"; the pink colour is due to partly-decomposed alkali felspar. A specimen (115) from the east wall of the Mittag-Leffler Glacier shows a mineralogical composition similar to that of the paragneisses further east, but the flakes of mica are more perfectly aligned and the rock is definitely schistose. Quartz and turbid alkali felspar are present in roughly equal proportions, forming a sutured granoblastic aggregate, individual crystals of which are somewhat elongated in the direction of schistosity. From its refractive index the felspar appears to be mainly albite with a little orthoclase. Muscovite occurs in well-shaped porphyroblasts, sometimes lying across the foliation, and biotite is fairly common; accessory minerals are epidote and sphene, with wisps of leucoxenized ilmenite.

Another specimen (123) from the same locality shows an alternation of coarsely micaceous and quartzose bands, the latter being completely free from felspar and possessing a dark resinous lustre in the hand specimen. In thin section this appearance is seen to be due to small flakes of muscovite and a little biotite, which are scattered through a fine sutured granoblastic groundmass of quartz and which show a nearly perfect parallelism, cutting across the borders between adjacent crystals. The coarser bands show contorted folia of muscovite and a little greenish chlorite, separated by areas of finely-ground quartz which give the appearance of a shear band. Calcite is an important constituent of this part of the rock. In a similar specimen (44) collected further to the south-west from the nunatak 2 miles north of Mount Sphinx, biotite occurs to the exclusion of muscovite.

A light grey felspathic quartzite (119) was collected from the tributary valley to the south of Mount Irvine, where it is interbedded with garnetiferous amphibolite, and forms irregular bands up to a thickness of 10 to 15 feet, the whole series being much shattered and jointed. A thin section shows areas of quartz and albite, in roughly equal proportions, recrystallized to an irregular mosaic and separated by bands of finely-granulated material, with some chlorite, ilmenite, and calcite, a little muscovite being locally intergrown with the chlorite.

From the high metamorphic zone of East Fjord comes a garnet-biotite-albite granulite (33), a specimen of which, collected by the 1930 expedition, appears as a dense greyish-pink rock with ill-defined augen of quartz and pink felspar and a few small red garnets. This particular hand specimen is traversed by a quartz vein 1 inch in width. Under the microscope it is characterized by a greater richness in ferromagnesian minerals than the above types, the most abundant being a greenish, partly chloritized biotite, in small flakes showing a rough parallelism, the secondary nature of the chlorite being indicated by occasional small needles of rutile embedded in it. One small, irregular-shaped garnet is visible, and greenish grains of epidote and clinozoisite are abundantly distributed, together with a few large crystals of sphene and a little iron ore. The mass of the rock consists of a coarse-grained aggregate of quartz and albite, the latter turbid but still showing multiple twinning. A similar rock (42) from the south-west corner of the nunatak N2 is richer in biotite and contains no garnets; here the felspar includes both oligoclase and orthoclase.

2. *Eastern Slates and Quartzites, with Associated Epidiorites.*

These, in the region under discussion, are confined to the eastern wall of the Lomme Bay Glacier, where they dip steeply but regularly to the east. Two main petrological types occur, namely, a series of dark flaggy or slaty rocks, usually with a pronounced cleavage, and interbedded with them various types of quartzites—white, buff, and pale green—in all of which the original clastic quartz grains are still visible under the microscope.

The more argillaceous members of the series show decided affinities with siltstones described by Tyrrell from Prince Charles Foreland. All have been subjected to a varying degree of low-grade metamorphism, and to the south, near the head of the glacier, the degree of recrystallization is such that the rocks are more appropriately termed biotite-hornfelses. In specimens from further north, however, the original bedding is often picked out by carbonaceous bands, and original clastic grains of quartz are still visible.

(*a*) *Argillaceous types.*—From the southern cliff of Hill "W" comes a hard compact, dark-grey rock (103, Fig. 3), with a poorly-developed, slaty cleavage. The original bedding is clearly visible in the form of a number of dark bands which average about twenty to the inch and are much puckered and contorted. These bands are proved by testing in an oxidizing flame to consist of carbonaceous matter. In thin section some bands are seen to be composed of finely divided opaque material which cannot be resolved into individual grains; many show overfolding and overthrusting on a small scale, and the rock has evidently developed a strain-slip cleavage. Other bands consist of isolated grains, and many of this latter type contain a considerable proportion of chlorite. The intervening areas are composed of finely-divided quartz and sericite, with a number of subangular clastic quartz grains; these may occur as isolated individuals, but more commonly as definite bands or as

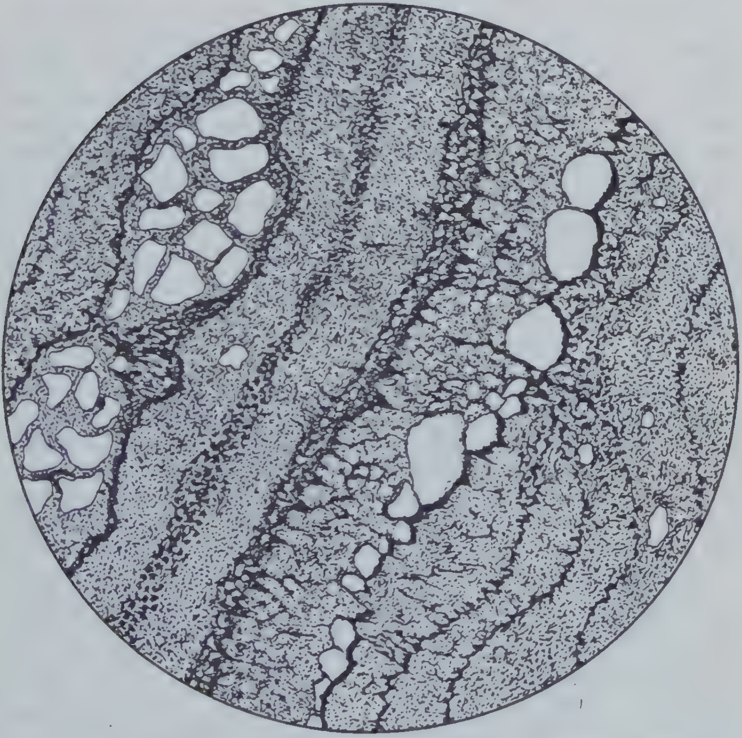

Fig. 3.—Contorted siltstone (103). Lomme Bay Glacier. × 14.

lenticular aggregates enclosed by the dark bands. The individual quartz grains commonly show strain shadows. There is no sign of biotite, and the rock is clearly in a less advanced state of metamorphism than those further south.

A similar rock (106) from a bluff 2 miles to the south shows a rather more advanced degree of recrystallization characterized by the presence of biotite and by the concentration of part of the sericite into well-shaped flakes of muscovite; the absorption of clastic quartz has, however, not yet taken place, and the bedding is still marked by carbonaceous bands.

From S1 at the head of the Lomme Bay Glacier comes a fine-grained black rock, which is easily scratched with a knife and is difficult to identify in the hand specimen, but which is resolved under the microscope into an aggregate of quartz and chlorite, with ragged flakes and patches of a light brown biotite. Some scattered flakes of muscovite are locally intergrown with chlorite which shows ultra-blue polarization tints. Minor amounts of an acid plagioclase, identified as albite-oligoclase, are present, and there is one small quartz-albite veinlet; small grains of magnetite occur in irregular, sub-parallel streaks. This rock is clearly due to the metamorphism of an argillaceous sandstone, and it seems probable that the metamorphism, which is of the hornfels type, is due to the proximity of the Chydenius granite massive or its underground extension.

(*b*) *Quartzites.*—A typical example (104) from the south side of Hill " W " is a hard, vitreous, slightly greenish rock which weathers into slabs about 1 inch thick, and consists of clastic grains of quartz set in a cement of finely-divided quartz and sericite. The quartz grains vary from subangular to rounded, show strain shadows, and are full of inclusions. The groundmass contains a little chlorite, and one small highly pleochroic grain is identified as tourmaline.

(*c*) *Epidiorites.*—As mentioned above, a massive epidiorite sill was discovered by the writer intercalated with the eastern slates and quartzites on the east side of the Lomme Bay Glacier. The hand specimen is a dense, medium- to coarse-grained, greyish green rock containing well-marked fibrous crystals of hornblende: these are plainly visible on the rusty red weathered surfaces of loose boulders. Under the microscope the ophitic structure of the original dolerite is well shown (101, Fig. 4). The augite has been transformed completely to pale porphyroblastic hornblende with poorly developed crystal faces and only feebly pleochroic with X = yellowish green, Y = green, Z = pale bluish green, $Z \wedge c = 23°$. The hornblende is partly altered to a pale green chlorite, with low birefringence in dark browns, accompanied by a little granular epidote. Small patches of biotite can be seen arising from the chlorite. The felspar is albite; it occurs as well-shaped lathes penetrating the hornblende, thus preserving the form of the original basic plagioclase, and also as irregular aggregates. Large crystals of leucoxenized ilmenite are present, partly altered to a turbid brown mineral, and some granular sphene. A coarser-grained variety shows laths of albite completely enclosed in hornblende, which also contains minute inclusions of clinozoisite. This specimen is traversed by veins of calcite, presumably due to the action of atmospheric solutions.

Petrologically and in its mode of occurrence this rock is quite distinct from the Cretaceous "diabase" sills of the Hinlopen Strait and Ice Fjord areas, which have been described in detail by Backlund.[1] These are normal dolerites, consisting essentially of pyroxene and plagioclase, with altered olivine; their age has been determined as Neocomian from evidence in the Wiche Islands, and it is only rarely that they are found intrusive into rocks younger than the Carboniferous. Nathorst [2] reproduces Nordenskiöld's section through

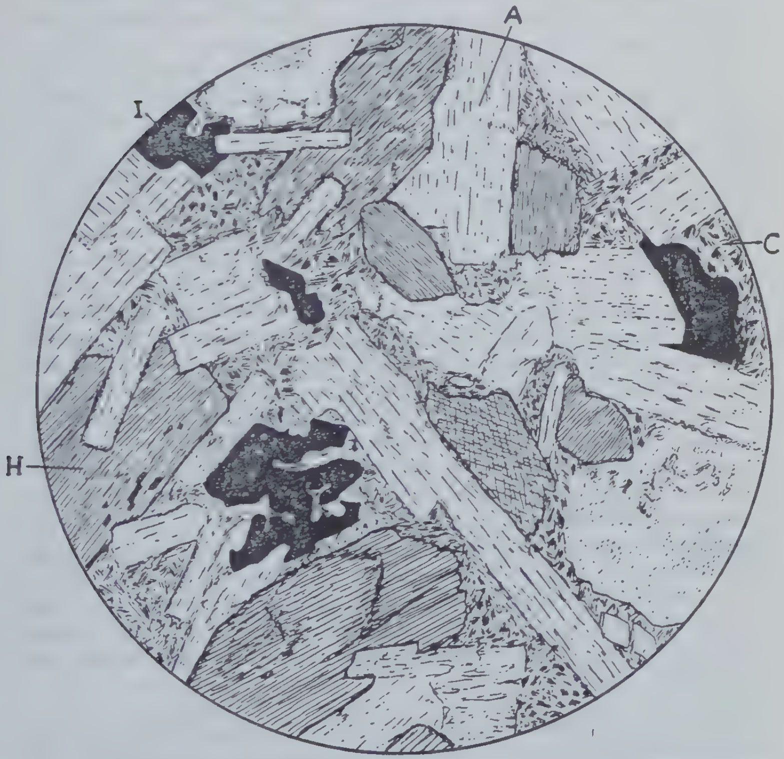

Fig. 4.—Epidiorite (101). Lomme Bay Glacier. × 14. A = albite; C = chlorite; H = hornblende; I = ilmenite.

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[1] "Les Diabases du Spitzberg Oriental": *Missions Scientifiques, etc.*, ii, § ix, 1907, B.I.

[2] Op. cit., 303.

Mount Hecla Hook, in which a "diabase" dyke is shown as intrusive into the Hecla Hook dolomites, but he makes no mention of basic rocks other than those of Cretaceous age, and it is to be assumed that he regards the dyke in question as Cretaceous.

That the epidiorite discovered by the writer on the eastern wall of the Lomme Bay Glacier is of Pre-Devonian age cannot be disputed. It conforms in dip and strike with the surrounding rocks and has every appearance of a sill which was intruded prior to the main Caledonian earth movements and which has been subsequently tilted and subjected to the same degree of low-grade metamorphism as the adjacent shales and quartzites. In particular the development of biotite from the chlorite is significant; this may be due to normal processes of regional metamorphism, but the writer is inclined to ascribe it to the influence of the Newton-Chernishev granite massive, which cannot be far distant. Unfortunately, the western limits of this intrusion have never been accurately delineated, and no traces of the well-known "Chydenius granite" were found on the 1932 expedition.

J. M. Wordie[1] records the presence of thick epidiorite sills in the region of Mount Monaco and Mount Jessie in Prince Charles Foreland, and these have been described in detail by G. W. Tyrrell,[2] who mentions two other occurrences, of peridotite and diabase at Recherche Bay and gabbro between Horn Sound and the Torell Glacier. He adds a suggestion that "these pre-folding basic igneous masses characterize the whole of the Hecla Hook outcrop in Western Spitsbergen", but so far as the writer is aware this is the first time that they have been recorded from the eastern belt. The two types differ somewhat in the scarcity of epidote and clinozoisite in specimens from the Lomme Bay Glacier, in which these two minerals appear to be derived from a secondary alteration of the hornblende rather than by saussuritization of the felspar: this may indicate a previous albitization, but it is equally possible that the lime-silicate mineral has passed into the hornblende, or that its mobility during metamorphism may account for its absence in the limited number of specimens examined.

The writer wishes to record his thanks to Mr. R. M. Jackson for permitting him to visit Spitsbergen as a member of the 1932 expedition, to Mr. W. G. Welchman and Mr. P. Lamartine-Yates for assistance in the field, to Dr. N. W. Pirie for the loan of his 1930 collection, to Professor O. T. Jones for permission to work at the Sedgwick Museum, Cambridge, to Mr. N. E. Odell for much valuable discussion, to Professor C. E. Tilley, Dr. A. Harker, and Mr. J. D. H. Wiseman for kind assistance in the petrological descriptions, and to Dr. G. W. Tyrrell, Mr. J. M. Wordie, and Dr. G. Slater for the loan of papers and rock sections.

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[1] "Present Day Conditions in Spitsbergen": *Geogr. Jour.*, lviii, 1921.

[2] "The Geology of Prince Charles Foreland, Spitsbergen": *Trans. Roy. Soc. Edin.*, liii, 1924.

The Precipitation of Calcium Carbonate on the Great Bahama Bank.

By MAURICE BLACK, Trinity College, Cambridge.

I. HYDROGRAPHICAL CONDITIONS.
II. CONCENTRATION OF CALCIUM SALTS ON THE BANK.
III. PHYSICO-CHEMICAL PRECIPITATION FROM CALCIUM BICARBONATE ON THE SHOALS.
IV. PRECIPITATION BY PLANTS AND INVERTEBRATES.
V. BIO-CHEMICAL PRECIPITATION FROM CALCIUM SULPHATE IN THE MANGROVE SWAMPS.

I. HYDROGRAPHICAL CONDITIONS.

IN the spring of 1930 the International Expedition to the Bahamas made several traverses over the shoals west of Andros Island in order to study the sedimentation of calcium carbonate in this region, and along three of these lines water samples were collected at regular intervals. The chlorine content of each of these samples was determined by the author in the Chemical Laboratory at the University of Princeton, New Jersey, and the total salinity was obtained by calculation.

When the results were plotted on a chart, as shown in Fig. 1, they at once revealed the presence of a central region of high salinity, bordered on the west by normally saline ocean water and on the east by a belt of slightly less concentrated water running along the west coast of Andros Island. The samples from the barrier reef off the east coast of Andros were unfortunately lost in transit, but the four values available from the determinations of previous investigators agree fairly closely in showing salinities between 36·2 and 36·6 per mille.[1] The rather low figures obtained south of North-west Point doubtless indicate the presence of a heavy fresh water drainage entering the sea from the Cut-off Creek area.

The sea floor over the Andros Block of the Great Bahama Bank stands only about 20 feet below water level, and maintains this elevation more or less uniformly right up to the edge of the shoals, where there is a sudden drop, usually at a gradient of one in three for the upper part of the slope, to depths varying between 2,500 feet and 6,000 feet. Thus the shoals are very sharply delimited and are surrounded by deep water with a surface salinity between 36 and 37, which is the normal salinity for water in the western Atlantic Ocean; except on the east side, there is no barrier to prevent free communication between the water over the banks with that of the open ocean.

The water temperatures on the banks are in general higher than those in the ocean, as would be expected from the small depth of

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[1] Dole and Chambers, "Salinity of Ocean Water at Fowey Rocks": *Carn. Inst. Wash.*, Pub. 213, 1918, 315. G. H. Drew, "On the Precipitation of Calcium Carbonate in the Sea by Marine Denitrifying Bacteria": *Carn. Inst. Wash.*, Pub. 182, 1914, 34–41.

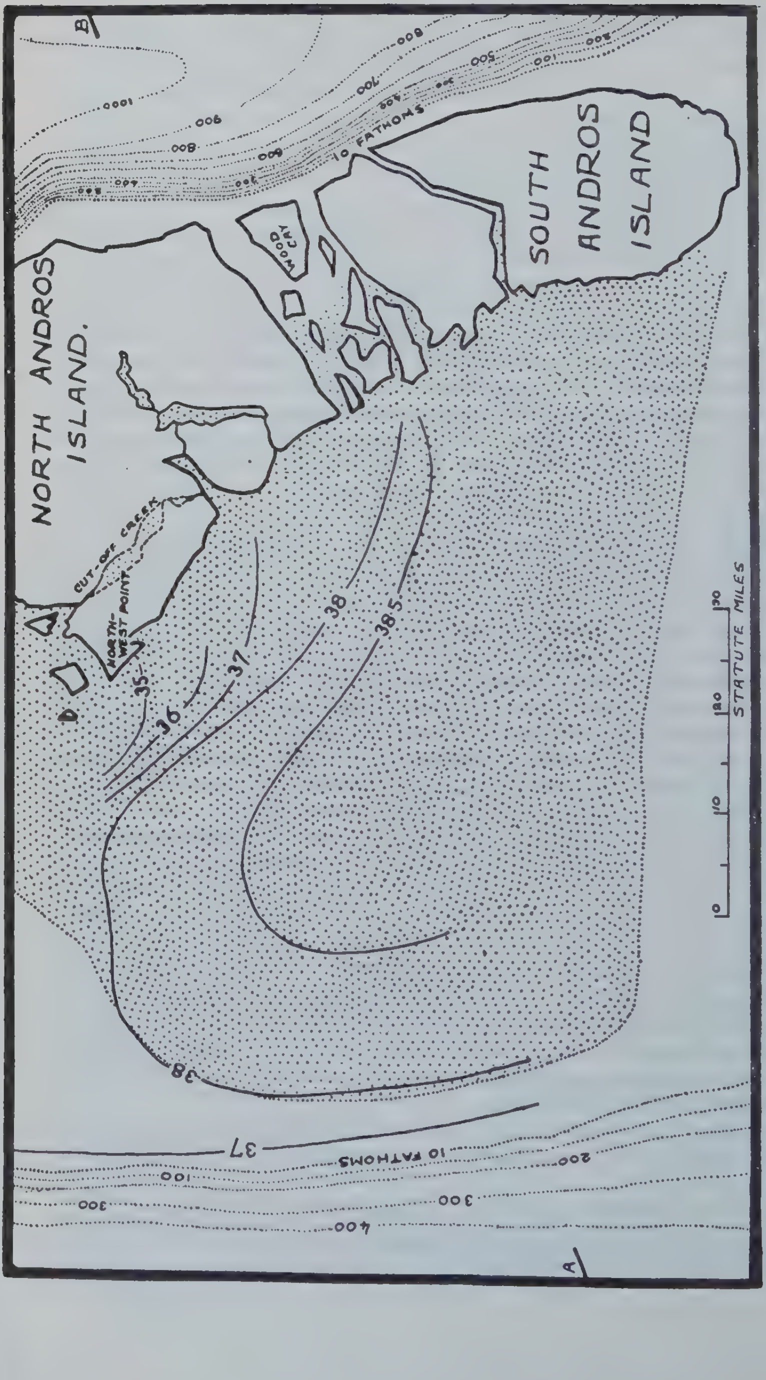

FIG. 1.—Salinity Chart of the shoals west of Andros Island. The isohalines are drawn in unbroken lines, showing the weight of total salts in parts per thousand. The part of the sea floor, over which the bottom deposits contain a high proportion of Aragonite mud, is stippled. Submarine contours are dotted and marked in fathoms.

water. The mean temperature of the Gulf Stream, as it flows through the Straits of Florida, ranges from 75° F. in the winter to 84° F. in the summer.[1] Off the west coast of Andros Island, in February and March, we found the temperature over the shoals to be from 75° F. to 81° F., whilst the mangrove swamps and inland lakes showed a greater fluctuation. Observations by Field and Fish during July, 1928,[2] showed an average of 86° F., and an inshore temperature between 90° F. and 92° F.

II. CONCENTRATION OF CALCIUM SALTS ON THE BANK.

On account of its extremely small depth and its great area the shoal region west of Andros Island appears to act as a vast evaporating pan, drawing in water with a salinity a little above 36 from the ocean, and concentrating it in the centre of the bank. The highest value obtained in the spring of 1930 was 38·7 parts per mille, but there is no reason for regarding this figure as a maximum, and it is extremely probable that in favourable circumstances the concentration becomes greater than this.

This increased concentration of salts on the west side of Andros Island is not particularly important so far as the more soluble compounds are concerned, but the very fact that any concentration at all is taking place is of fundamental importance with respect to those salts which are nearest to saturation in the ocean water of these latitudes. Since the region is one of limestone sedimentation, it is of particular interest so see how far the oceanographical conditions in the shoal water may be responsible for bringing about the precipitation of calcium carbonate.

It is at once apparent that an area of increased salinity in the centre of the bank implies loss of water by evaporation there, and consequently a drift of water in from the ocean on to the banks, bringing dissolved salts of calcium along with it. Thus, whatever the agency of precipitation may be, there is a constant supply of calcium salts for it to work upon, and the accumulation of a permanent precipitate of calcium carbonate is to be expected. That the warm surface waters of the tropical and subtropical seas are saturated with respect to calcium carbonate may be regarded as well established; the evidence upon which this conclusion rests has been presented and discussed by Johnston and Williamson,[3] and need not be repeated here. It follows, then, that any concentration of the brine is, in itself, sufficient to raise the calcium carbonate content of the water beyond the saturation point, and precipitation becomes possible.

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[1] *West Indies Pilot,* **1,** 1929, 34.

[2] Field and Fish, "The Princeton-Buffalo Expedition to the West Indies": *Science,* lxix, 1929, 222–3.

[3] Johnston and Williamson, "The Role of Inorganic Agencies in the Deposition of Calcium Carbonate": *Journal of Geology,* 1916, 734–5. See also additional experimental evidence obtained by R. C. Wells, *U.S.G.S.,* Prof. Paper 120–A, 1918, 9.

Quite independently of the increased concentration of salts due to evaporation, the rise in temperature to which the water is subjected as it travels towards the centre of the bank is sufficient to bring the calcium carbonate content above the saturation point. This is due to the decreased solubility of carbon dioxide with an increase in temperature, and this in turn lowers the solubility of calcium carbonate. Taking into account both the increased concentration of calcium carbonate and its decreased solubility with a rise of temperature, we can now calculate the quantity of solid carbonate which should be precipitated from each cubic metre of water when it has been drawn across the shallows from the open ocean to the centre of the bank. For this purpose, the solubility figures are taken from the tables prepared by Johnston and Williamson [1] for solutions of calcium carbonate in sea water under atmospheric conditions, i.e. with carbon dioxide at a partial pressure of 0·00032.

Taking the winter range of temperature and salinity, we have Gulf Stream water at 75° F. drawn on to the banks, and raised to 81° F. on the shoals, and at the same time being concentrated from a salinity of 36 per mille [2] to 38·5 per mille. The solubility of calcium carbonate in sea water is 56·96 gm. per cubic metre at 75° F.; when the salinity has risen to 38·5 parts per mille, the volume of the original cubic metre is reduced to $\frac{36 \cdot 0}{38 \cdot 5}$ cubic metres, and the solubility at 81° F. has dropped to 54·24 gm. per cubic metre. Hence for every cubic metre of water which comes on to the banks from the Gulf Stream, only $\frac{36 \cdot 0}{38 \cdot 5} \times 54 \cdot 24 = 50 \cdot 73$ gm. of calcium carbonate remains in equilibrium in solution, and a precipitate of 6·23 gm. of solid carbonate should be formed. Whether this material is at once liberated as solid carbonate or not, it is evident that conditions in the central part of the bank are highly favourable for precipitation.

In the absence of observations on the velocity of flow towards the centre of the bank, it is not possible to calculate directly from the concentration of the brine the rate at which this precipitate is accumulating. The annual increase of excess carbonate can, however, be estimated from the calculated evaporation losses from the water surface, as shown below on page 461.

In the sheltered shoal water west of Andros Island the clear condition of the water during calm periods suggests the possibility that, whilst the concentration of calcium carbonate increases, this salt is not immediately precipitated, but that the solution may remain supersaturated with respect to calcite until the separation of solid carbonate is stimulated and localized. Such a tendency for a solution of calcium carbonate to reach a considerable degree of supersaturation, has frequently been noticed in experimental work, and, in certain circumstances, the process of concentration may be carried far beyond the true equilibrium point before actual precipitation begins to take place.[1]

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[1] Johnston and Williamson, op. cit., 733.

[2] This is the mean salinity of Gulf Stream water off the western edge of the Great Bahama Bank, obtained by Dole and Chambers (op. cit., 313) from a large number of salinity determinations which they made from samples collected in the Straits of Florida.

In addition to this purely physical condition of supersaturation, it has been shown that stagnant natural waters are capable of holding an abnormally high content of calcium carbonate ; this they are enabled to do by virtue of their unusually large concentration of carbon dioxide, produced by the respiration of animals and bacteria. For example, Carter and Beadle [2] found that the stagnant waters in the swamps of the Paraguayan Chaco contained as much as 100 c.c. of carbon dioxide per litre at temperatures between 30° C. and 35° C. The normal concentration at such a temperature for a solution in equilibrium with the atmosphere is of the order of 0·25 c.c. per litre, and the excessive quantity in the swamp water was found to be due to vigorous bacterial decay in the bottom muds ; the gas was retained in solution partly in combination with alkalies, but largely because there was insufficient circulation of the water to allow the uncombined gas to escape. Similarly, Klähn [3] found that the waters of the Sildemower See held an abnormally high content of calcium carbonate in solution without precipitation taking place, and attributed this to the abundance of carbon dioxide fed into the water by the bacteria of the bottom mud of the lake.

III. PHYSICO-CHEMICAL PRECIPITATION FROM CALCIUM BICARBONATE ON THE SHOALS.

For considerable periods of time the water over certain parts of the bank remains undisturbed, and even the finest sediment is allowed to sink, so that the water becomes remarkably clear and transparent. The shoals immediately west of North Andros and South Andros Islands form such areas, and probably owe their remarkable quiescence to their protection by these islands from tidal and wind-impelled currents. In such stretches of water, the concentration of calcium carbonate probably mounts above its saturation value during quiet periods, and no appreciable precipitation takes place until the next heavy storm, when the water becomes violently disturbed, and the attainment of equilibrium is encouraged by a combination of circumstances, chief amongst which are the stirring up of innumerable nuclei from the bottom and the expulsion of any excess of carbon dioxide through the agitation of the water. Thus there is found, in the lee of Andros Island, an area where the sea is floored by a deposit consisting largely of aragonite mud (see Text-fig. 1). The precipitate takes the form of extremely small needles of aragonite, which remain loose and uncemented on the sea floor.

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[1] Johnston, Merwin, and Williamson, "The Several Forms of Calcium Carbonate": *American Journ. of Science*, xli, 1916, 505–6. Johnson and Williamson, *Journ. Amer. Chem. Soc.*, xxxviii, 1916, 975.

[2] "The Fauna of the Swamps of the Paraguayan Chaco in relation to its Environment": *Linnean Society's Journal Zool.*, xxxvii, 1930, 226 et seq.

[3] H. Klähn, "Senone Kreide mit und ohne Feuerstein": *Neues Jahrbuch f. Min.*, lii, Beilage-Band, Abt. B., 1925, 402–454.

The rate of formation of this deposit is a matter of some interest, and the data available are sufficient to give a rough estimate. The simplest method of obtaining such a figure is to calculate, from meteorological data, the theoretical rate of evaporation from the water surface. Since the water in this region is saturated with respect to calcium carbonate, this estimate at once gives a value for the precipitate formed as a result of concentration.

Rates of evaporation from large water surfaces have been calculated from the results of prolonged observations on the losses from reservoirs, and although the connection between these figures and those expressing the corresponding meteorological conditions is naturally somewhat complicated, it is possible to derive a workable formula. The most suitable of these, for the present purpose, is that worked out by Fitzgerald[1] from a long series of observations at Chestnut Hill Reservoir, Boston. Adapting this formula for use with metric units for the vapour pressure and the rate of evaporation, we have :—

$$E = [0{\cdot}014\ (V - v) - 0{\cdot}00005\ (V - v)^2] \times [1 + 0{\cdot}67w^{\frac{2}{3}}]$$

where E = evaporation in millimetres per hour
V = maximum vapour pressure in millimetres of mercury, corresponding to the temperature of the water.
v = partial pressure of water vapour in the air.
w = wind velocity in miles per hour.

In using this formula to calculate the rate of loss by evaporation on the Bahama Bank, a large number of assumptions and approximations must be made, so that the resulting estimate is to be regarded as little more than suggestive of the order of magnitude of the true figure.

Weather conditions in the Bahamas are distinctly marked off into two seasons ; the winter has strong winds and a low rainfall (24 cm.), whilst the summer has lighter winds and most of the year's rainfall (103 cm.). It is thus necessary to calculate the rate for each season separately ; for accurate results, it would be essential to calculate the evaporation for each hour of the day separately, but the meteorological data available are not sufficiently detailed for this purpose, and it is not feasible to do more than take averages for day and night conditions separately.

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[1] Desmond Fitzgerald, "Spontaneous Evaporation": *Trans. Amer. Soc. Civil Engineers*, xv, 1886, No. 340, 581.

Using data derived from various sources, but wherever possible from the observations made by the International Expedition, we get the following average values :—

	WINTER		SUMMER	
	Day	Night	Day	Night
$V-v$	6·2	7·4	8·0	10·1
w	10·17	9·00	8·25	5·83
E	0·3136	0·3535	0·3673	0·3995
Gross Evaporation for Season	1·444 metres		1·675 metres	
Rainfall	0·241 ,,		1·029 ,,	
Net Loss	1·203 ,,		0·646 ,,	

These figures show that, although the summer rainfall replaces much of the volume lost by evaporation, it fails to do so completely, and a certain diminution in volume must still take place.

Assuming complete precipitation of the calcium carbonate originally held in solution by the water now lost by evaporation, and assuming also that the water drawn on to the bank from the surrounding ocean is ultimately raised to the same temperature and concentration as the water it replaces, we can now estimate the weight of precipitate formed during each season.

	Winter	Summer
Temperature of Gulf Stream . .	75° F.	84° F.
Corresponding Solubility of Calcium carbonate in gm. per cubic metre	57	53
Net Loss by Evaporation in metres .	1·203	0·646
Weight of Precipitate in gm. per square metre	67·01	34·24

This gives a total annual precipitation of 101·25 gm. on each square metre of sea floor, corresponding to a thickness of 0·0338 mm. per year. In the centre of the shoals west of North Andros Island, Aragonite needles make up about 20 per cent of the sediment, the other constituents being shells of foraminifera, chips of mollusc shells, and some limestone grains; this would bring the total annual sedimentation up to the order of 0·166 mm. It is probable that if the precipitated material washed out of the mangrove swamps could be taken into account, a rather higher figure would have to be substituted, but it is unlikely that this additional material, spread out over the bank, would raise the rate of deposition high enough to equal the rates at which certain deep-sea deposits are believed to be forming. The Globigerina Ooze, for instance, is believed to be accumulating over the telegraph cables in the North Atlantic at the rate of 1 inch in ten years, or 2·54 mm. per year [1]; a similar rate of deposition (2·0 mm. per year) has been determined for the sediments in the central part of the Black Sea.[2] If these figures are taken at face value, the remarkably low rate of sedimentation in the shallow water of the Bahama Banks calls for an explanation, which is probably to be sought in the paucity of plankton over the shoals. Skeletons of plankton organisms contribute practically nothing to the sediment directly, and, judging from the investigations made by Dr. Charles Fish, the plankton is too sparse to provide food for more than a thinly-scattered benthonic fauna, which normally would supply the bulk of the sediment under water of this depth.

Those parts of the bank which lie in the track of currents of any kind are floored by a sediment which contrasts strongly with the aragonite mud of the more sheltered waters. This deposit consists of a beautifully rounded limestone sand, often entirely free from any material of smaller grain size. The grains are spherical or ellipsoidal, and possess a very characteristic structure, with a large nucleus of extremely fine-grained limestone, enclosed within a few oolitic layers of aragonite, usually two or three. These deposits were revealed by our bottom samples to be best represented at the edge of the bank, and also in line with the several straits or bights which separate Northern from Southern Andros. These parts of the sea floor are continuously under the influence of strong currents, which keep the sediment in constant agitation and have sufficient transporting power to winnow away all traces of finer material; the currents through the bights are partly tidal and partly driven by the prevailing easterly winds, whilst at the edge of the bank the tidal wash is particularly strong. Thus the sea water of these tracts is kept thoroughly well mixed and stirred, and has no chance to remain stagnant whilst the temperature rises and the brine becomes concentrated. Consequently, there is less chance of supersaturation, and it is probable that the excess calcium carbonate which is deposited upon the grains of limestone sand in concentric coats of aragonite comes out of solution step by step as the concentration of the solution progresses.

IV. PRECIPITATION BY PLANTS AND INVERTEBRATES.

There can be no doubt that plants play some part in relieving the sea water of its excess of calcium carbonate, though how important they may be in this respect is not known. The most

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[1] Murray and Peake, "On Recent Contributions to our Knowledge of the Floor of the North Atlantic Ocean": *Royal Geog. Soc.*, 1904, 21.

[2] A. D. Archanguelsky, "On the Black Sea Sediments and their importance for the study of Sedimentary Rocks": *Bull. Soc. Nat. Moscow*, Section Géologique, v, 1927.

active calcium extracting plants in the shallow water of the Bahama Banks are certain members of the Codiaceae, which build up limy skeletons. On the shoals west of Andros Island, *Penicillus*, *Rhipocephalus*, *Udotea*, and *Halimeda* are particularly abundant, and in certain places, disjointed segments of *Halimeda* and *Penicillus* make up an appreciable part of the sediment; this state of affairs is exceptional, however, and the quantity of carbonate extracted by these plants cannot form any large proportion of the total amount precipitated. The Cyanophyceae, which are extremely important as sediment binders above low water-mark, do not appear to exert any appreciable influence on the precipitation of calcium carbonate in this region, for the sediment which is found in intimate contact with them in the tidal belt can nearly always be shown to be detrital.[1] Further inland, where the Cyanophyceae are still more important, they seem to have very little chance of bringing about the precipitation of carbonate, for they are covered by an extremely thin layer of water, which is liable to acidification by fresh rain-water, and the total effect is more likely to be a loss than a gain of solid carbonate. It is significant that species belonging to the Rivulariaceae, so frequently associated with calcium precipitation in other parts of the world, were not found in the algal marshes of Andros Island. The dominant filamentous forms were all found to belong to the Scytonemataceae or to the Oscillatoriaceae.

A further quantity of calcium carbonate goes to form the shells of invertebrates, but this again is probably small. The shallow water contains a distinctly sparse plankton, which appears to be almost devoid of organisms with calcified skeletons; planktonic foraminifera, for example, were not found in any of the shallow water hauls taken by Dr. Fish.[2]

The benthonic fauna is also scanty and patchily distributed. Bottom samples of sediment sometimes consist largely of the shells of benthonic foraminifera and molluscs, but these are mostly decayed or broken, and living specimens are comparatively rare. Bottom living organisms appear to be abundant only where there is an outcrop of bare rock on the sea floor. Such outcrops are not frequent and are of small area; where they do occur, they are reported to be colonized by alcyonarians, sponges, and calcareous algae, and to support a fairly rich molluscan fauna. It is probable that much of the dead shell material which is spread over the rest of the bank has been derived from these comparatively well-colonized areas. The conclusion to be drawn from a study of the plankton and benthos in the shoal water west of Andros Island is that organic agencies here are extracting only a small amount of calcium carbonate from the water as it passes over the banks.

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[1] This question is dealt with in some detail in a paper entitled "The Algal Sediments of Andros Island, Bahamas": *Phil. Trans. Roy. Soc.*, Ser. B, ccxxii, 1933, 165–192.

[2] For details of the plankton hauls taken in the course of this expedition, see "Report on Oceanology" by Dr. Charles Fish, in R. M. Field, "Geology of the Bahamas": *Bull. Geol. Soc. of America*, 1931, 765–6 and 770–2.

V. BIO-CHEMICAL PRECIPITATION FROM CALCIUM SULPHATE IN THE MANGROVE SWAMPS.

The most important centres of precipitation appear to be provided by the mangrove swamps of the west coast of Andros Island, where a special combination of circumstances gives rise to an environment peculiarly favourable for the accumulation of precipitated calcium carbonate. In these localities there can be little doubt that the actual separation of solid carbonate is brought about through the activity of bacteria living upon the organic débris which abounds in these swamps. The work of Bavendamm[1] has shown that not only is the bacterial flora an extremely rich one, but also that several of the most abundantly represented species are capable of affecting the chemistry of the water in such a way that calcium carbonate is precipitated.

The precipitation of calcium carbonate on an extensive scale through the agency of bacteria has been a subject of controversy since the possibility of such a process was discussed by Drew in 1914.[2] The history of this discussion has been summarized by Bavendamm[3] and by Twenhofel,[4] and need not be repeated here. The misunderstandings which have prolonged the argument appear to have arisen from a lack of sufficiently accurate field work. This deficiency has been to a great extent made good through the work of Dr. Bavendamm, the bacteriologist to the International Expedition. So long as the well oxygenated water of the sea was taken as the site of bacterial precipitation, it was easy to show, as Lipman[5] has done, that although there are bacteria present which, in certain other circumstances, could bring about precipitation, they are present in such small numbers as to be incapable of doing so in the open sea. As soon as the mangrove swamps were examined bacteriologically, and their enormous wealth of anaerobic bacteria had been discovered, Lipman's criticisms ceased to hold good, and it can be no longer doubted that precipitation takes place on an extensive scale in these sheltered waters.

The principal reactions leading to the separation of solid carbonate appear to be those which increase the alkalinity of the solution.

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[1] W. Bavendamm, "Die Mikrobiologische Kalkfällung in der tropischen See": *Arkiv für Mikrobiologie*, 1932, 205–276.

[2] G. H. Drew, "On the Precipitation of Calcium Carbonate in the Sea by Marine Denitrifying Bacteria": *Carnegie Inst. Wash.*, pub. 182, vol. v, 1914.

[3] Bavendamm, op. cit.; a full bibliography is presented on pp. 270–6.

[4] Twenhofel, *Treatise on Sedimentation*, 2nd ed., 311–17.

[5] C. B. Lipman, "A Critical and Experimental Study of Drew's Bacterial Hypothesis of Calcium Carbonate Precipitation in Sea Water": *Carnegie Institution of Washington*, pub. 340, 1924, 181–191; and "Further Studies on Marine Bacteria": *Carn. Inst. Wash.*, pub. 391, 1929, 231–248.

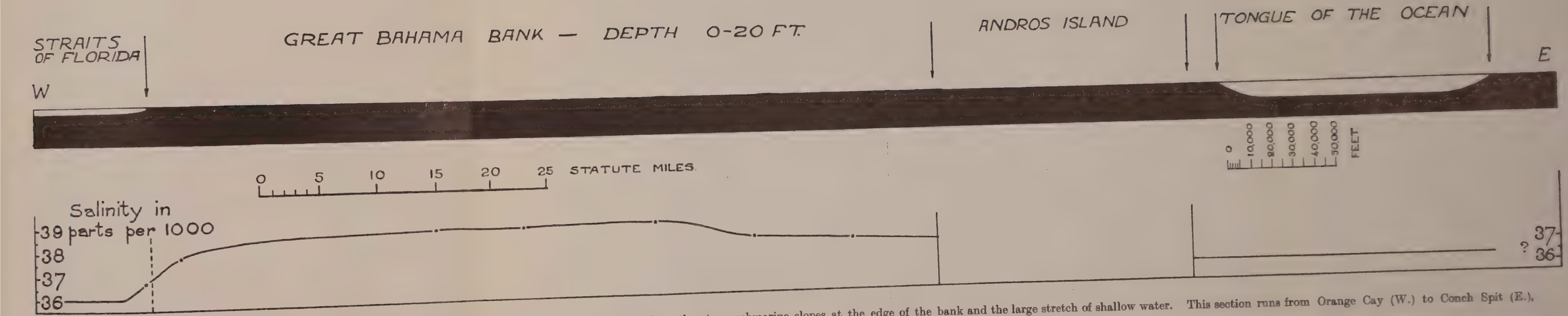

FIG. 2.—Upper Diagram: Topographical profile of the Great Bahama Bank, drawn to true scale to show the steep submarine slopes at the edge of the bank and the large stretch of shallow water. This section runs from Orange Cay (W.) to Conch Spit (E.), a line almost parallel with the upper margin of Fig. 1, and 10 miles to the north.

Lower Diagram: Graph to show the increased salinity over the shoals west of Andros Island. The curve is drawn from the salinities of a series of samples collected on 9th April, 1930, at stations along the line marked A–B on Fig. 1. The horizontal scale has been slightly reduced in order to bring the points representing the edge of the bank directly underneath the corresponding points in the upper figure.

[*To face p. 464.*

Most important in this respect are the ammonifying bacteria, which are the chief agents of calcium precipitation in the mangrove swamps of Andros. Thus we get the reaction—

$$Ca(HCO_3)_2 + 2NH_3 = CaCO_3 + (NH_4)_2CO_3.$$

The same reaction is also brought about by the nitrate-reducing bacteria; these were considered by Drew to be responsible for most of the precipitation on the west coast of Andros, but recent work has shown them to be less important in this respect than the ammonifiers.

Since the sea water in the Bahamas is saturated or even supersaturated with calcium carbonate, the above reaction is doubtless the first stage in the precipitation of aragonite in the mangrove swamps, but further reactions are capable of drawing upon the calcium sulphate of the sea water, and thus have a more plentiful supply of raw material available. The water of the Gulf Stream carries about 57 gm. of calcium carbonate per cubic metre at 75° F. under normal atmospheric conditions, whereas the amount of calcium sulphate is as much as 1,300 gm. per cubic metre. The slight increase in sulphate content, brought about by evaporation of the water as it passes over the open shoals between the Gulf Stream and Andros Island, is by no means sufficient to cause precipitation of gypsum, because the concentration in the original solution is too far below that required for saturation. Once the water is carried by tidal currents into the mangrove swamps, however, the sulphate is at once open to chemical attack through the agency of bacterial reactions.

The sulphate-reducing bacteria directly, and the ammonifiers indirectly, are responsible for the precipitation of aragonite from the calcium sulphate in the swamp waters. Bacteria of both these groups are reported by Dr. Bavendamm to be present in large numbers in the coastal swamps of Andros.

$$CaSO_4 + 8H = CaS + 4H_2O.$$
$$CaS + CO_2 + H_2O = CaCO_3 + H_2S.$$

This reaction is doubtless responsible for the large volume of hydrogen sulphide which is frequently present in the bottom muds of the mangrove swamps.

The activity of the ammonifying bacteria is believed to be still more important, and the resulting ammonium carbonate is probably the principal precipitating agent—

$$(NH_4)_2CO_3 + CaSO_4 = CaCO_3 + (NH_4)_2SO_4.$$

A significant fact, which emerges from Bavendamm's investigation of the bacteria in these localities, is that the forms which are most actively concerned in the precipitation of aragonite are forms already well known from soils or estuarine muds in areas of non-calcareous sedimentation in other parts of the world; it thus appears that the accumulation of precipitated carbonate is made possible, not by the presence of specially-adapted bacteria, but rather by the high rate of metabolism of the micro-organisms present in warm, subtropical waters, together with the saturation or supersaturation of this water with calcium carbonate, so that a newly-formed precipitate is not liable to re-solution as it would be in cooler or deeper water.

The immediate fate of the precipitate formed in the mangrove swamps depends largely upon water conditions at the time of precipitation, or shortly afterwards. In rough weather, aragonite crystals are stirred up from the floor of the swamp and held in suspension, so that material is carried out on to the open shoals at every tide so long as the water is sufficiently disturbed. During quieter periods most of the precipitate appears to remain in the mangrove swamps and lakes, which show strong indications of being slowly silted up. Actual settling of the precipitate is believed to be comparatively rapid, provided that the water remains undisturbed, partly because the reactions take place at the contact between the bottom muds and the overlying water, thus leaving the precipitate a minimum distance to fall, and partly because the swamp water is so highly charged with organic matter that co-precipitation must greatly accelerate the rate of fall.[1] An examination of the mangrove swamps and sedge marshes of Andros Island supports the view that this sediment continues to accumulate until the swamps and tidal lakes concerned become completely converted into sedge marshes. It thus appears that much of the precipitated aragonite does not reach a marine environment until it has first of all been deposited under swamp conditions and the strata so formed have been subjected to later erosion and redeposition. Details of this process, which is at present taking place along certain parts of the coastline of Andros, will be included in an account of the resulting marine sediments now in course of preparation.

New Evidence on the Origin of Breccias and Conglomerates in the Warwickshire Coalfield: The Mount Nod Boreholes, Coventry.

By F. W. Shotton, M.A., F.G.S.

(PLATE XXIV.)

DURING the last two years the Coventry City Corporation has put down three boreholes, for water supply purposes, near Mount Nod Farm, on the north side of Broad Lane, 2 miles 5 furlongs W. 6° N. of the centre of the city.

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[1] Samples from the west coast of Andros Island were examined by Professor P. G. H. Boswell, who found that the sediment "contains a notable quantity of organic colloids intimately mixed with it". P. G. H. Boswell, "The action of Colloids in precipitating Fine Grained Sediments": Geol. Mag., 1930, 380.

The first (No. 1 of this paper) was in the nature of a trial-hole, after which two wells have been bored, the first (B.H. 2) 6 feet to the west of No. 1, and the second (B.H. 3) 6 feet to the east. The three records are almost identical, and the publication of the details of No. 1 is all that is required except for a few notes in cases where the other two differ. The cores have been personally examined by the writer, who is indebted to the Coventry City Corporation for permission to publish details. Whilst making this acknowledgment, the writer also wishes to express his thanks to Professor L. J. Wills for much useful criticism of this paper.

MOUNT NOD BOREHOLE, NO. 1.

Surface height approximately 364 feet O.D.

	Thickness		*Depth.*		*Remarks.*
	ft.	*in.*			
1. Red clay and Boulder clay	14	0	14	0	*Base of Drift.*
2. Red marl, sandy in places	35	0	49	0	—
3. Grey sandstone . .	5	0	54	0	—
4. Red "fish-eyed" marl with occasional thin red or grey sandstones.	71	0	125	0	*Base of Tile Hill Marls.*
5. Rather coarse, red felspathic sandstone.	4	0	129	0	—
6. Very fine conglomerate .	2	0	131	0	Pebbles not exceeding ¼ in. in length.
7. Rather coarse, red felspathic sandstone, with occasional bands of very fine conglomerate.	55	0	186	0	—
8. Grey and purple sandstone.	1	0	187	0	With poorly preserved leaves resembling *Cordaites.*
9. Red marl, with thin sandstone bands.	25	0	212	0	—
10. Red sandstone with thin marls.	4	0	216	0	—
11. Red sandstone with fine conglomerate.	8	0	224	0	Pebbles to 1 in. in diameter.
12. Fine conglomerate . .	2	6	226	6	Pebbles to 1 in., subrounded, but difficult to extract from core. Mainly cherts, with some Silurian sandstone.
13. Alternating thin beds of red marl and red and grey sandstone.	17	6	244	0	—
14. Red marl with "fish-eyes". Sandy towards base.	30	0	274	0	—
15. Well-cemented red or grey sandstone, with a few marl bands, traces of fine conglomerate, and pellet-rock.	46	0	320	0	—

	Thickness *ft.*	*in.*	*Depth.*		*Remarks.*
16. Alternating beds of sandstone, sandy marl and marl, with some pellet-rock. Sandstone predominates, especially towards the base.	95	0	415	0	—
17. Hard red marl, often "fish-eyed", with thin beds of sandy marl and sandstone.	82	6	497	6	—
18. Grey and variegated sandstone, with thin marls and pellet-rock.	17	6	515	0	—
19. Red "fish-eyed" marl .	46	6	561	6	—
20. Grey sandstone . .	1	0	562	6	*Top of Allesley Conglomerate Phase.*
21. Coarse red sandstone with fine conglomerate.	3	6	566	0	—
22. Fine conglomerate . .	2	0	568	0	Pebbles to ¾ in. in length. Sample B of p. 471.
23. Red sandstone . .	1	6	569	6	—
24. Breccia	2	0	571	6	Fragments to 1½ in. Sample C of p. 471.
25. Hard sandstone, irregularly cemented with calcite, very fine conglomerate in bottom half.	21	0	592	6	—
26. Very fine conglomerate .	2	6	595	0	Pebbles too small, and too well cemented, for adequate examination.
27. Red sandstone . .	1	9	596	9	—
28. Conglomerate with many marl pellets.	1	9	598	6	Pebbles to 1¼ in. Sample E of p. 471.
29. Red sandstone . .	3	6	602	0	—
30. Conglomerate . .	2	6	604	6	Pebbles to 1½ in. Sample F of p. 471. *Base of Allesley Conglomerate Phase.*
31. Hard red sandstone, with traces of very fine conglomerate.	23	9	628	3	—
32. Coarse red sandstone with thin marl bands.	15	9	644	0	—
33. Red sandstone with some pellet-rock.	14	6	658	6	—
34. Red marl . . .	2	6	661	0	—
35. Coarse red sandstone, very fine conglomerate and pellet-rock.	36	0	697	0	—
36. Conglomerate . .	2	0	699	0	Pebbles to 1¼ in. Sample G of p. 471.
37. Grey sandstone and conglomerate.	0	6	699	6	Pebbles to 1¼ in. Sample H of p. 471.
38. Red marl . . .	3	0	703	6	—

BOREHOLE NO. 2. ADDITIONAL NOTES.

Bed 11. Includes a conglomerate between 222 ft. 6 in. and 223 feet (Sample A of p. 471). This is not the same horizon as Bed 12 of B.H. 1, for this occurs, unchanged in position, in B.H. 2.

Bed 13. Between the levels of 240 ft. 9 in. and 243 feet, several large pieces of a silicified tree trunk were brought up in purple sandstone and marl. This is referred to later.

Bed 24. Instead of 2 feet of simple breccia, as in B.H. 1, the sequence between 569 and 571 feet was as follows :—

Breccia, exactly as in B.H. 1 . . .	11 inches
Well-rounded conglomerate with green sand and clay matrix. Many chert pebbles .	2 inches
Breccia of local calcareous sandstone in red clay	11 inches

Bed 36. Includes, between the levels of 692 ft. 6 in. and 694 feet, a purple sandstone with abundant pieces of squashed haematized wood, resembling *Cordaites.*

The borehole finishes at 705 feet, with 6½ feet of red marl.

BOREHOLE NO. 3. ADDITIONAL NOTES.

Bed 9. Marl with sandstone bands containing wisps of fine conglomerate.

Bed 11. A conglomerate between 219 and 221 feet, 2½ feet above Bed 12, is apparently the same as sample A of Bed 11, B.H. 2. A sample was taken for pebble analysis.

CORRELATION OF THE BOREHOLES WITH THE EAST WARWICKSHIRE SEQUENCE.

The solid rocks (2–4) first penetrated are the Tile Hill Marls.[1] In a previous paper [2] I defined the base of this group (following on the work of the Geological Survey) as being where clays give place downwards to a group of thick sandstones with intervening marls, and I estimated from surface exposures alone that this sandstone group comprised about 300 feet of beds above the Allesley Conglomerate. In the Mount Nod boreholes I unhesitatingly ascribe the 43 feet of sandstones, conglomerates, and breccias (20–30) between the depths of 561 ft. 6 in. and 604 ft. 6 in. to the Allesley Conglomerate; but an ascent of 436½ feet, and not 300, is required before a reasonable base to the Tile Hill Marl Group can be drawn. The subdivision of the borehole records can therefore be made as follows :—

	Thickness: Feet.	*Position referred to O.D.*
Boulder Clay . . .	14	364 to 350
Tile Hill Marl Group .	111	350 to 239
Sandstone Group above Allesley Conglomerate . . .	436½	239 to −197½
Allesley Conglomerate . .	43	−197½ to −240½
Beds between Allesley and Corley Conglomerate. .	100½	−240½ to −341

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[1] T. Eastwood, W. Gibson, T. C. Cantrill, T. H. Whitehead, "The Geology of the Country around Coventry": *Mem. Geol. Surv.*, 1923.

[2] F. W. Shotton, "The Geology of the Country around Kenilworth" *Q.J.G.S.*, lxxxv, 1929, 167–222.

Comparing the level of the Allesley Conglomerate in the borehole and at its outcrop in Allesley village, it is seen to have a dip of slightly over 5° in a direction a little west of south.

DETAILED EXAMINATION OF THE RUDACEOUS BEDS OF THE BOREHOLES.

The occurrence between the levels of 569 ft. 6 in. and 571 ft. 6 in. of a band of breccia (24) immediately attracted the writer's attention. This breccia (Fig. 1) is closely similar to the Warley breccia of the Birmingham district and to the thin breccia bands of Kenilworth, particularly when these can be examined in an unweathered state. The finding of such a band here was entirely unexpected. The few surface exposures of the Allesley Conglomerate show well rounded pebbles, while the conglomerates of Beechwood and Gibbet Hill occur many hundreds of feet above the Allesley horizon, and yet precede the phase of breccia deposition as exemplified by the Kenilworth breccias. In the Mount Nod borehole itself, beds of more-rounded pebbles, grading into typical conglomerates, occurred both above and below the breccia. Hence it appeared that, at Allesley Conglomerate times, there had been a temporary foretaste of the conditions which were to become normal during Kenilworth Breccia times.

In order to assess the significance of this appearance of breccia, samples of it and of the other pebbly horizons in the borehole were collected and their pebbles examined. The chief constituents are few in number. They are: (1) limestones; (2) cherts, variable in colour and texture; (3) compact brown and purplish-brown sandstones, sometimes with fossils; (4) coarse quartzite; (5) decomposed igneous rocks and tuffs; and (6) a baked, red or green material, very fine in texture, which is probably an indurated shale, though it may be a very fine ash.

(1) and (2) are regarded as Lower Carboniferous, (3) is Valentian, (4) is Cambrian, while (5) and (6) I consider to be Pre-Cambrian (see previous papers).

The table on the next page summarizes the results of the examination.

From these figures certain conclusions may be drawn.

(1) Considering first the amount of Silurian sandstone pebbles present, the percentage is seen to keep between the low limits of 3 and 17, except in Bed 36, where 54 per cent is encountered. This horizon, then, is clearly different from the others in the borehole. I have elsewhere given evidence[1] to show that a ridge of land existed on the prolongation of the Nuneaton anticline, and provided

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[1] F. W. Shotton, "The Conglomerates of the Enville Series of the Warwickshire Coalfield": *Q.J.G.S.*, lxxxiii, 1927, 604–621. "The Geology of the Country around Kenilworth": *Q.J.G.S.*, lxxxv, 1929, 167–222.

Bed No.	*Level in B.H.*	*General description*	*No. of. pebbles examined*	*Per cent of different constituents*			
				Carbons	*Sil.*	*Camb.*	*Pre–C.*
A. 11 (B.H. 2) (B.H. 3)	222 ft. 6 in.–223 ft. 218 ft. 6 in.–221 ft.	Conglomerate, rounded to subrounded, except Pre-Cambrian material, which is subangular. Calcareous cement. Many marl and limonite pellets.	100	62	12	–	14
B. 22	566 ft.–568 ft.	Conglomerate subrounded to subangular. Calcareous gritty matrix.	116	48	3	2	44
C. 24	569 ft. 6 in.–571 ft. 6 in.	Breccia. Pebbles angular or subangular. Pre-Cambrian more angular than Carboniferous cherts. Calcareous matrix.	178	17	5	–	75
D. 24*a*	Middle two inches of 24, in B.H. 2.	More rounded than 24 as a whole, due to numerous well-rounded cherts.	74	30	5	4	61
E. 28	596 ft. 9 in.–598 ft. 6 in. = 598 ft.–599 ft. in B.H. 2.	Angular (Pre-Cambrian) to subrounded (cherts). Considerable number of clay pellets.	298	30	10	1	54
F. 30	602 ft.–604 ft. 6 in.	Conglomerate, subangular to subrounded.	133	31	17	1	44
G. 36 (B.H. 1) (B.H. 2)	697 ft.–699 ft. 698 ft.–698 ft. 6 in.	Fairly well rounded. Silurian sandstones constitute all the big pebbles (up to 1½ in.).	143	20	54	3	20
H. 37	699 ft.–699 ft. 6 in.	Well-rounded conglomerate. Bleached green.	77	42	13	4	36

the great amount of Silurian material in the Corley conglomerate. It was not an appreciable source of material for the Arley-Exhall conglomerate, which was derived from the west, and its influence had waned by the time the Allesley Beds were laid down. So, in the 43 feet of beds in the borehole (20–30) which I ascribe to the Allesley conglomerate there is no evidence of the Nuneaton ridge influencing sedimentation; but Bed 36, a hundred feet below the Allesley conglomerate and probably about 50 or 100 feet above the main Corley pebble-development, is the latest case yet known of the effect of the eastern land-ridge on sedimentation in the area. From this level upwards, as far as we know, the Nuneaton ridge must have been of low height and probably itself covered with sediments.

All the material of Bed 36 is not derived from the east, the Lower Carboniferous material and the Pre-Cambrian both coming probably from a more distant western source. It is significant that the pebbles of Silurian sandstone in this bed are chiefly between 1 and 1½ inches long, whereas the other constituents rarely exceed ½ inch in size.

Immediately below Bed 36 in Borehole No. 1 is a 6 inch band of green conglomerate (37). It consists essentially of Avonian and Pre-Cambrian detritus, and so is akin to the horizons in the Allesley Conglomerate, a hundred feet higher. Beds 36 and 37 therefore represent a time when land masses were supplying material to the East Warwickshire cuvette from both sides, and at the particular point under consideration a torrent of water from the west swept over the floor of the basin immediately before one from the east. (In Borehole No. 2 the thin layer of western material was not present; the lowest part of conglomerate 36 resembled Bed 37 of B.H. 1 in that it was bleached, but its constituents were those of layer 36.)

(2) Considering now all the pebbly horizons of the borehole except layer 36, it is seen that the proportion of Avonian material starts at 42 per cent in bed 37, decreases progressively to 17 per cent in bed 24, and then rises to 62 per cent in 11. Concurrently the Pre-Cambrian material shows a movement in the opposite direction, and reaches its maximum value of 75 per cent also in layer 24. The increase of one important constituent as another decreases is not surprising, but the consistency of the change is striking. But another series of facts gives particular significance to these changes of pebble-proportions. Bed 37 is a perfect conglomerate, 30, 28 (Pl. XXIV, B), and 24*a* consist of a mixture of rounded and angular pebbles, 24 is a typical breccia (Pl. XXIV, A), 22 is subrounded, while 11 approaches again to a true conglomerate. In other words, as Pre-Cambrian material takes the place of newer pebbles, so does the deposit change from a conglomerate to a breccia; as the reverse trend happens, so conglomerates are again found. The rule applies equally well to any particular bed. Thus 11 has the appearance of a conglomerate, but if the Pre-Cambrian pebbles are separated out, they are all seen to be angular or subangular; while

the small number of Avonian and Silurian pebbles in the breccia (24) are quite well rounded.

Two salient facts are apparent—there is a close correlation between the petrology of the pebbles and their angularity, and there is also a cyclical change in time from conglomerate formation to a breccia and back again to the deposition of conglomerate. In order to attempt an explanation of these facts, it is necessary to visualize the physiographic conditions of these Late-Carboniferous times. We may imagine a low-lying basin of deposition flanked, in the west at least, by high mountains of recent origin. The climate being semi-arid, the crests of these hills would be subjected mainly to mechanical weathering, with the production of angular detritus. Lower down the slopes, however, the scree-fragments would tend to become less angular, for here there would be small streams, incapable of moving the larger pieces of rock but carrying sand or mud which would abrade their projections. It is necessary to imagine these small streams to explain the thicknesses of sandstone and clay which lie between successive rudaceous horizons.[1]

Periodically there would be heavy rainfall and sudden torrents down the hills, and on these occasions much of the blanket of scree on the mountains would be swept out into the intermont basin, probably at such a rate (particularly if the basin were dry at the time) as to effect little further rounding of the pebbles, which would be deposited in much the same shape as they had previously possessed on the mountain slopes. Now, since the rounded pebbles are essentially of Avonian and Valentian rocks, whereas Pre-Cambrian material is angular, it follows that if the above explanation of the conditions is true the newer rocks must have existed on the low slopes of the hills, with Pre-Cambrian on the crests. But this is precisely the arrangement to be expected on a recently-formed, partly-eroded anticlinal.

In connection with the ideas outlined above, the detailed section of Bed 24 in Borehole 2 (see p. 469) is illuminating. It may be interpreted as showing the progressive deposition, by one rush of water of, first, angular fragments of local material torn up from the dried lake-basin; then of rounded Avonian material from the more-distant hill-flanks; and finally of angular Pre-Cambrian fragments from the most-distant mountain crests.

It is thus seen that the formation of breccias or conglomerates may be regarded as having been controlled by the chief type of parent-rock and its position of outcrop on the hills, rather than by any great alteration of general aridity.[1]

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[1] It is probable, of course, that the close jointing, shattering, and indurated nature of the Pre-Cambrian rocks would lend themselves to the production of angular fragments, while the softer and soluble Avonian limestones and the rounded chert concretions would have originally a greater tendency to produce round pebbles. It seems less likely, however, that the hard Silurian sandstones would have taken on their well-worn shape unless they had been subjected to more attrition than the Pre-Cambrian material.

It is still necessary to explain the cycle of deposition which the rocks exhibit, and the writer believes that this is most simply done by invoking a minor cycle of uplift and erosion on the mountain mass which was the source of the coarse detritus. Up to the level of Bed 24, with its maximum of Pre-Cambrian material, we may imagine that the parent land-mass was undergoing uplift more rapidly than could be counterbalanced by erosion, with a steepening of the average surface gradient and a bigger contribution of angular pebbles from the axially-outcropping rocks. Bed 24 probably represents the time when erosion had become equal to uplift, and from then onwards the former factor increased in relative importance and caused a return to the earlier conditions of conglomerate-deposition.

The first half of the minor cycle in the borehole is exactly similar in miniature to the large-scale change from conglomerate to breccias which occurs in most of the Midland Coalfields. The writer believes that these pebble-beds resulted from the growth of neighbouring mountain chains which reached their maximum elevation in Clent-Kenilworth breccia times ; but that this uplift was spasmodic, with periods of extra activity followed by relative quiescence, which will explain smaller effects such as that visible in the Mount Nod borehole.

THE BEARING OF THE DISCOVERY OF THIS BRECCIA UPON THE PERMIAN QUESTION.

The appearance of this typical " Permian " breccia in the middle of a conglomerate sequence has some bearing upon the question of the classification of these Midland breccias. Professor Boulton has given good evidence [2] that in the Birmingham area the Clent breccia lies unconformably upon the Upper Carboniferous sequence, and his conclusion is now accepted by several officers of the Geological Survey. He therefore classifies these breccias as Permian in age and has, moreover, stated that the unconformity below the breccia is greater in magnitude than that between it and the Bunter. In the Kenilworth district occur two breccia bands which closely resemble the Clent breccia in general appearance and in detailed pebble-content, but the writer's mapping has revealed no unconformity with the underlying conglomerates of the Upper Carboniferous. The writer's belief is that in East Warwickshire there was an intermont basin which was the scene of continuous deposition from Middle Coal Measure times until after the laying down of the

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[1] It is significant that even in the Kenilworth breccias (representing a time when conglomerate-deposition had ceased) the small proportion of Avonian and Silurian material is very well-rounded.

[2] W. S. Boulton, " The Rocks between the Carboniferous and the Trias in the Birmingham District " : *Q.J.G.S.*, lxxxix, 1933, 53–86.

Kenilworth breccias. The surrounding mountains were in a state of intermittent movement, and on their flanks was deposited the Clent breccia, with a basal unconformity—and probably interformational breaks too—as a result of these repeated movements. Meanwhile, in the East Warwickshire cuvette, sedimentation proceeded without appreciable pauses. It was not until after the phase of breccia formation that earth-movement of a regional rather than local character affected the Midlands, and formed, as one of its effects, the southward pitching syncline of the East Warwickshire coalfield. The fact that here the Keuper Sandstone oversteps from the Ashow Group, south of Kenilworth, on to Lower Cambrian, near Nuneaton, implies a destruction of several thousand feet of sediments, and the passage of a great interval of time between the Ashow Group and the Lower Keuper.

Against the writer's view that the Kenilworth breccias are closely connected stratigraphically with the underlying conglomerates, it has been suggested that a "masked" unconformity may exist, not detected by the mapping.[1] It is reassuring, therefore, to encounter the band of breccia in the Mount Nod borehole. It occurs within a conglomerate series whose Carboniferous age is generally accepted, and it is succeeded by the thick Tile Hill Marls and the Gibbet Hill Group, in both of which conglomerates occur, before the Kenilworth breccias are encountered in the upward sequence. If, therefore, a "Permian" type of breccia can occur as the result of gradual transition at the Allesley horizon, it strengthens the view that no discontinuity need be present at the much more important change from conglomerates to breccias which occurred later. The writer, therefore, would still classify the Kenilworth-Clent breccias as Carboniferous, upon his interpretation of their diastrophic relationships. It would be idle to pretend, however, that either the word "Carboniferous" or "Permian" has any real meaning in the Midlands, where there is no reliable fossil evidence. All that is implied in the above classification is that the phase of breccia-deposition is a continuation of a type of sedimentation which began as early as Keele times at least. The writer would not attempt to forecast whether, if palaeontological classification ever becomes possible, the division between Carboniferous and Permian would be above or below the Kenilworth breccias.

NOTE ON THE FOSSIL WOOD IN BED 13 OF BOREHOLE 2.

Several large pieces of petrified wood, probably all part of one tree, occurred between the depths of 240 ft. 9 in. and 243 feet in the second borehole. The trunk must originally have been about 20 inches in diameter, but compression following decay of the pith has reduced it to an oval section. The preservation is siliceous, with haematite filling up many of the cells. A number of sections have been cut and sent to Professor J. Walton, who kindly identified it as cf. *Dadoxylon brandlingii*, L. & H. The state of preservation is not sufficiently perfect to refer the specimen with certainty to the above species, but there is probably little doubt of it in view of the finding of large silicified trunks in Allesley village and near St. Lawrence's Well, Meriden,[1] which were identified by Kidston as this species. These latter specimens, however, occur in a sandstone about 40 feet above the Allesley conglomerate, whereas the Mount Nod example is 320 feet above this horizon. It is thus the highest record of *Dadoxylon* wood from the Warwickshire Coalfield. Unfortunately the find cannot be used as palaeontogical evidence in dating the beds, for Professor Walton informs me that *Dadoxylon brandlingii* has been recorded from the Permian of Frankenberg, Saxony, as well as from Carboniferous strata.

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[1] W. S. Boulton, "The Rocks between the Carboniferous and the Trias in the Birmingham District": *Q.J.G.S.*, lxxxix, 1933, 54.

EXPLANATION OF PLATE XXIV.

SAMPLES OF PEBBLY BEDS FROM THE MOUNT NOD BOREHOLE.

A. Bed 24. Breccia, made up largely of Pre-Cambrian material.
B. Bed 28. A mixture of well-rounded Avonian and Silurian pebbles and sub-angular Pre-Cambrian material.
C. Bed 36. Conglomerate, mainly of Silurian and Avonian material.

REVIEW.

TEXT-BOOK OF PALAEONTOLOGY. By KARL A. VON ZITTEL. Translated and edited by Dr. CHARLES R. EASTMAN. Vol. II. Second English edition revised, with additions, by Sir ARTHUR SMITH WOODWARD. With 533 illustrations. pp. xviii + 464. London: Macmillan and Co., Ltd., 1932. Price 30*s*.

AFTER a somewhat long interval the second volume of the new English edition of "Zittel" has been published, vol. iii, dealing with the Mammals, having been issued in 1925. The original character of the work is still maintained, but Sir Arthur Smith Woodward has revised and considerably enlarged the text. Moreover, the more recent literature has been added to the original bibliography, but, to save space, some of the older references have been omitted in cases where these are mentioned in the new papers referred to. In the part dealing with fishes, Sir Arthur, as the leading authority on the subject, could safely rely on his own knowledge, but in writing the sections on reptiles and birds he has availed himself of the help of Dr. Broom, Mr. Pycraft, and other specialists. The result is an admirably balanced account of the

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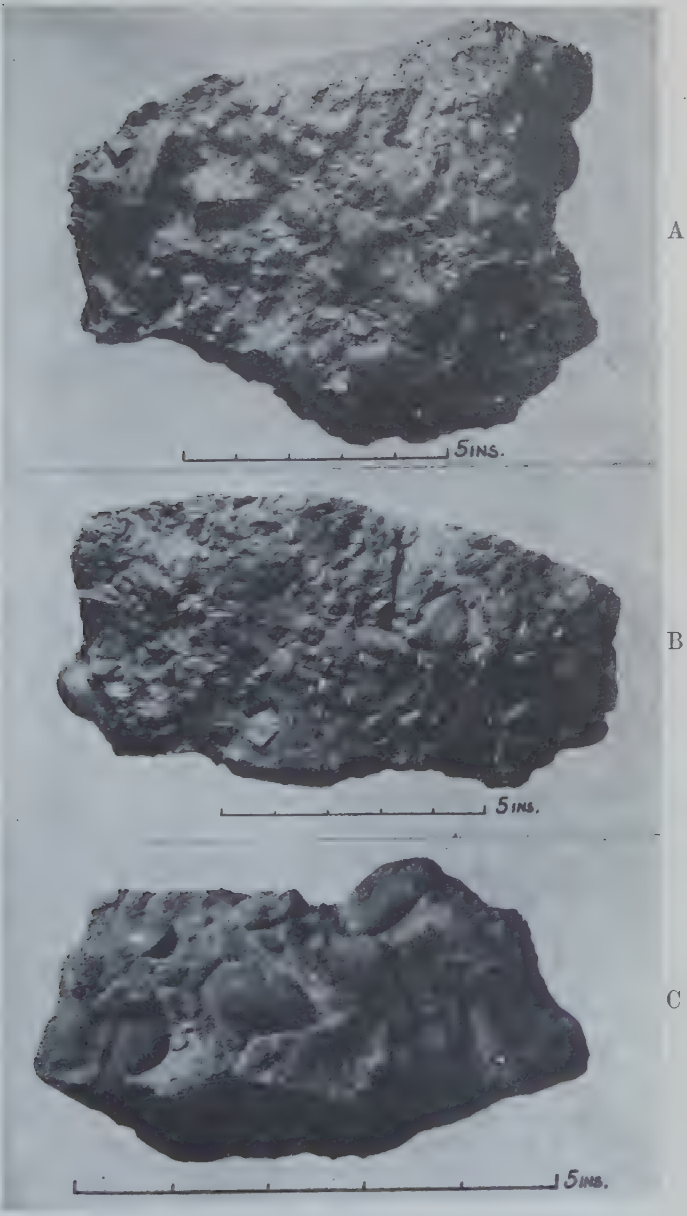
[1] T. Eastwood, W. Gibson, T. C. Cantrill, T. H. Whitehead, "The Geology of the Country around Coventry": *Mem. Geol. Surv.*, 1923, 86, 87.



[*To face p.* 476.

SAMPLES OF COARSE BEDS FROM THE MOUNT NOD BOREHOLES, COVENTRY.

palaeontology of the lower Vertebrates, with a good deal that is new in textbook form. Thus the newer extensive work on the Ostracoderms, the Stegocephalia, and the Reptilia of the Permian and Trias is included.

Owing to the book being based so largely on the original " Zittel ", the classification is apt to be conservative or, as some would say, antiquated. Thus, we find in contrast to every modern text-book of zoology, *Amphioxus* is referred to the " Leptocardii " as a class of Vertebrates instead of being placed outside that division, and the Cyclostomata are included as a sub-class of fishes instead of being given equal rank with the rest of the Vertebrates which are generally called Gnathostomata. The possibility should not be altogether rejected, however, that these forms are degenerate Vertebrates, a view which is supported by the parasitic habit of the Cyclostomes, in which case the classification herein adopted will be fully justified.

There is an interesting section on the range and distribution of fossil fishes. Here it is pointed out that the abrupt break in development, which is observable in most groups of plants and animals at the close of the Palaeozoic epoch, is conspicuous among fishes, the Triassic forms differing much from the Permian, though there are some exceptions. With the commencement of the Cretaceous another important change is seen, the Ganoids becoming more and more displaced by the Teleosteans, while with the beginning of the Tertiary the fish approximate closely to those of the present era. It is not generally known that the soft parts of fishes have sometimes been preserved fossil, that remains of the ovary have been found in two genera of Teleostei, that the kidney may be discerned in a fossil Elasmobranch, and that fossilized muscle is not uncommon.

In the account of the Amphibia which follows, it is shown that the temnospondylous Stegocephali (as first pointed out by Cope) were probably the direct ancestors of the Reptilia (being closely similar to the Cotylosauria). They are found in the Carboniferous, Permian, and Triassic. Some members of this group, however, have direct affinities to the modern Amphibia (as shown by Watson). Very few representatives of the modern orders have been found fossil.

Just as there can be little or no doubt that certain of the Stegocephali were the ancestors of the reptiles, so it would now seem certain that the Theromorph reptiles contain genera from which are descended the Mammalia. According to Broom, the small rat-shaped Ictidosauria were " almost Mammals ". The account of the reptiles concludes with a summary of their range and distribution. Among many other facts of interest it is recorded that the Theromorpha, which contained the mammalian ancestors, have become extinct by Jurassic times, and that by the beginning of the Tertiary all the characteristic Mesozoic reptiles had disappeared.

Men of science have paid little attention to avian palaeontology, and the relative scarcity of fossil remains of birds is hardly sufficient reason for the neglect of this subject by ornithologists. As a matter of fact, representatives of nearly all the orders (or as they are called here, sub-orders) of Aves have been found fossil. The great gap between the Jurassic *Archaeopteryx* and the toothed birds of the Cretaceous is here remarked upon as well as the somewhat less gap between the latter and Tertiary birds. Of these it is shown that most species " are not only representatives of well-known families, but often belong to the same genera as species now living in the same geographic area in which the fossils occur ". It is remarked, further, that " this is in marked contrast with what we find in the Mammalia, for not a family of those occurring in the Eocene, and few in the Miocene, are represented by living species ".

The entire book is a mine of information, much of which has a bearing on theories of organic evolution and the distribution of land and sea at various past periods. In discussing such problems undue emphasis is sometimes laid on the present distribution of plants and animals and too little account taken of their distribution in former epochs of the earth's history. Thus, the similarity of the distribution of the primitive Arthropod *Peripatus*, the Dipnoan fishes, and the Struthious birds has been cited as evidence of former land bridges or of continental drift, while according to one theory these animals are regarded as of the nature of " living fossils " which owe their existence to their isolation. In such connections the facts recorded in this book showing that the Dipnoi were widely spread in Europe and elsewhere from the Devonian onwards (the living genus *Ceratodus* itself being found in the Bunter Sandstone of Germany), and that the Struthious or Ratite birds have not been found fossil until the Tertiary when they occurred in nearly all the principal continents, are often overlooked and their relevance disregarded.

Zoologists and geologists alike are under a deep obligation to Sir Arthur Smith Woodward for the part he has played in the issue of this second English edition of " Zittel ".

F. H. A. M.

REPORTS AND PROCEEDINGS.

British Association, Leicester, 1933.

Abstracts of Papers read in Section C.—Geology.

Dr. A. Raistrick: "The microspores of coal and their use in correlation."

The microspore-content of coal samples can be extracted and isolated by the use of solvents such as Schultz solution, followed by ammonia, which remove the oxidizable coal matrix and leave the spore exines and microspores untouched. The microspores are mounted for micro-examination, and are dealt with statistically, in the same way as tree pollen in peat in investigations. Microspore types are very varied and very definite, and their determination in the micro-separations is a matter of precision. There is good evidence that particular coal seams are characterized, over a wide area, by an assemblage of certain groups of microspores present in fairly definite proportions. The principal microspore types are illustrated and described.

Professor G. Hickling and Mr. C. E. Marshall: "Recent studies of plant structure in coal."

Improvements in the technique of section-cutting and photography have made it possible to show that coal consists largely of plant-remains in which the details of the original structure are preserved with remarkable perfection. This detail, in some respects, far exceeds that which can be observed in the familiar calcified or silicified petrifactions or coal-balls, since in the coal most of the original substance of the plant remains, while in the petrifaction it has been replaced. By the study of isolated sheets of bark and portions of wood which are preserved as coal in the coal-measure shales the microstructure of the plants can be studied in relation to their external form. The bark-structures of *Lepidodendron*, *Bothrodendron*, and *Sigillaria* have been so studied, as well as certain woods. In certain cases it appears possible to demonstrate conclusively that the existing coal consists in part of the original plant-substance and in part of additional organic material which has been absorbed by the plant after death.

Mr. A. T. J. Dollar: "The dike-swarm of Lundy."

The Lundy dike-swarm comprises 122 dominantly vertical rock-sheets of basic and intermediate composition which occur respectively in the proportion of 91 : 9. It includes typical crinanites, olivine- and analcite-dolerites, quartz-dolerites, and tholeiites, together with orthophyres, vitreous and non-vitreous andesites and pitchstones. Extreme types are represented by metallic ores, gabbroid rocks and very vitreous pitchstones. The assemblage as a whole is distinctly Tertiary in affinity.

These dikes cut both the coarse granites and Devonian sediments of the island with an average frequency of twenty-six per linear mile of coast. The mean thickness of an individual sheet is about 4 feet, but the basic varieties range between ½ inch and over 20 feet, while the less abundant types of intermediate composition generally exceed 10 feet in breadth. The width of the swarm is approximately coincident with the north-south length of the island, and a crustal extension of 3 per cent has been produced in this direction by the minor injections.

Apart from intermediate and basic intrusions are numerous thick and thin inclined sheets of micrograníte which are confined to the major granites of the island, while many quartz veins cut both the granites and sediments. The two kinds of microgranites are remarkable for their similarity to granophyric rocks of the Mourne Mountains, Ireland.

The distribution of intermediate and basic dikes is rigidly controlled by jointing and fan-fractures. The latter radiate from centres which appear to lie on submarine planes of weakness. Magnetic properties of the basic dikes have been investigated and are comparable with those of corresponding British Tertiary rocks.

CORRESPONDENCE.

NOTE ON A CARBONIFEROUS GENUS.

Sir,—Mr. L. R. Cox has drawn my attention to the fact that the generic name *Knightia* which I have given to some Carboniferous gasteropods in the *Quart. Journ. Geol. Soc.*, lxxxix, pt. 2, 1933, 118 and 119, is preoccupied by D. S. Jordan (Univ. California Publ., *Bull. Dept. Geology,* v, 1907, 136) for a genus of fossil fish. I would therefore suggest the name *Knightella* instead.

J. Longstaff.